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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: TR-3615
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER: 9
4. TITLE (and Subtitle): 6 SUBSONIC WIND TUNNEL TESTS OF A CANARD-CONTROL MISSILE CONFIGURATION IN PURE ROLLING MOTION.
5. TYPE OF REPORT & PERIOD COVERED: ~~Continuing~~ Technical rept. 1 July 1975-31 October 1976
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 Samuel R. Hardy
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Surface Weapons Center, Dahlgren Laboratory (DK-21), Dahlgren, VA 22448 — 12 78p.
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 17 62332N, F32323, WF3232301, DK04AA102 — F32310 WF32310000
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Systems Command, Washington, DC 20360
12. REPORT DATE: 11 June 1977
13. NUMBER OF PAGES: 87
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 14 NSWC/DL-TR-3615
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Subsonic wind tunnel tests
Canard-control missile

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The description and run log of subsonic wind tunnel tests on a canard-control missile in pure rolling motion are presented. Test data for the body plus canard plus tail configuration (with 0-deg deflections) of the canard-control missile are shown. The nonlinear second-order differential equation of motion used in the "global" nonlinear least-squares analysis of the test data is discussed. Nonlinear aerodynamic coefficients extracted from the test data are presented and discussed. The results for the body plus canard plus

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tail configuration with 0-deg deflections showed that the linear roll damping moment coefficient increases slightly with the angle of attack up to about 20 deg, as predicted. However, at 30 deg the coefficient decreases significantly.

FOREWORD

This technical report documents wind tunnel tests and preliminary data analyses which were conducted from 1 July 1975 to 31 October 1976, under a program to investigate the rolling motion of cruciform canard-control missiles at moderate angles of attack.

This work was supported by Mr. W. C. Volz of the Naval Air Systems Command (AIR-320C) under AIRTASK A03W-350D/004B-6F32-300-000.

The Army Air Mobility Research and Development Laboratory, Moffet Field, California, provided testing facilities and personnel for the wind tunnel tests.

Timely, successful completion of the tests was due to Ms. G. A. Laub, test engineer, and the other staff members of the Army Air Mobility Research and Development Laboratory. Critical repairs to the test equipment were made by members of the NASA, Ames Research Laboratory staff. Photographic support was provided by W. A. Shipman, Naval Surface Weapons Center, Dahlgren Laboratory (NSWC/DL), Photographic Laboratory, Dahlgren, Virginia.

Mr. R. E. Meeker, Naval Weapons Center (NWC), China Lake, California, provided valuable consultation and advice during the tests.

This report was reviewed for technical accuracy and approved by Mr. Frank Stevens, Aeromechanics Branch, Dr. Frankie G. Moore, Head, Aeromechanics Branch, and Mr. Herman Caster, Head, Exterior Ballistics Division of the Warfare Analysis Department.

Released by:

Ralph A. Niemann

RALPH A. NIEMANN, Head
Warfare Analysis Department

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INTRODUCTION

The work presented herein is part of a joint program with the Naval Weapons Center (NWC), China Lake, California, to improve the methods of predicting the rolling motion of non-roll-controlled guided missiles. Improved prediction of rolling motion may simplify guidance systems and provide some further insight into the roll characteristics of canard-control missiles that fly at high angles of attack.

The specific objective of the Naval Surface Weapons Center (NSWC) in this program is to experimentally determine dynamic roll moment coefficients (roll damping) of a cruciform, canard-control missile airframe. The experimental data are to be used by NWC to evaluate NWC-sponsored prediction techniques of roll damping characteristics of cruciform, canard-control missiles. The experimental data will serve as a data base for comparison with "theory."

NSWC had previously developed the analysis tools needed to extract static and dynamic roll moment coefficients as a function of angle of attack from experimental angular roll data. A "global" nonlinear least-squares fitting procedure was developed to extract nonlinear roll moment coefficients from single-degree-of-freedom rolling motion data. The equation of motion used in the procedure was developed for cruciform-finned (body plus tail) missile configurations. The fitting procedure and the equation of motion were used successfully to extract nonlinear roll coefficients of cruciform-finned and wrap-around-finned missile configurations. It seemed logical to extend the fitting procedures to more complex configurations such as the canard-control configuration, even though the equation of motion was not specifically developed for guided-missile configurations.

NSWC was tasked to conduct wind tunnel tests and analyze part of the test data in Fiscal Years 76 and TQ. Only the test data for the body plus canard plus tail configuration (with 0-deg deflections) were analyzed during the past year. This technical report summarizes the work performed in Fiscal Years 76 and TQ.

EQUATION OF MOTION

The "global" nonlinear least-squares fitting procedure used to extract the nonlinear roll moment coefficients requires a second-order nonlinear differential equation of motion which contains adequate coefficients to describe the roll characteristics of the test configuration in order to fit the observed data. To the writer's knowledge, there has been no complete formulation of a pure rolling equation of motion for a canard-control missile at high angles of attack. Therefore, it was

decided to use the equation of motion developed for the cruciform body plus tail configuration (Reference 1). This previously developed equation was thought to be adequate for canard-control configurations which have 90-deg roll symmetry. It was assumed that the body plus canard plus tail configuration with 0-deg deflections would exhibit rolling motion characteristics similiar to cruciform body plus tail configurations.

The basic characteristics of free rolling motion of cruciform body plus tail were described by Nicolaides in References 2 and 3. The basic characteristics, "linear" rolling motion, roll "slow-down," roll "lock-in," roll "break-out," and roll "speed-up" occur as the missile's angle of attack increases from 0 to 90 deg. Figure 1 shows the roll characteristics as a function of angle of attack for a typical cruciform-finned missile with fin cant at low subsonic speeds. In this wind tunnel case, the missile has only a roll degree-of-freedom. Therefore,

$$p = \dot{\gamma}$$

where γ is the roll orientation.

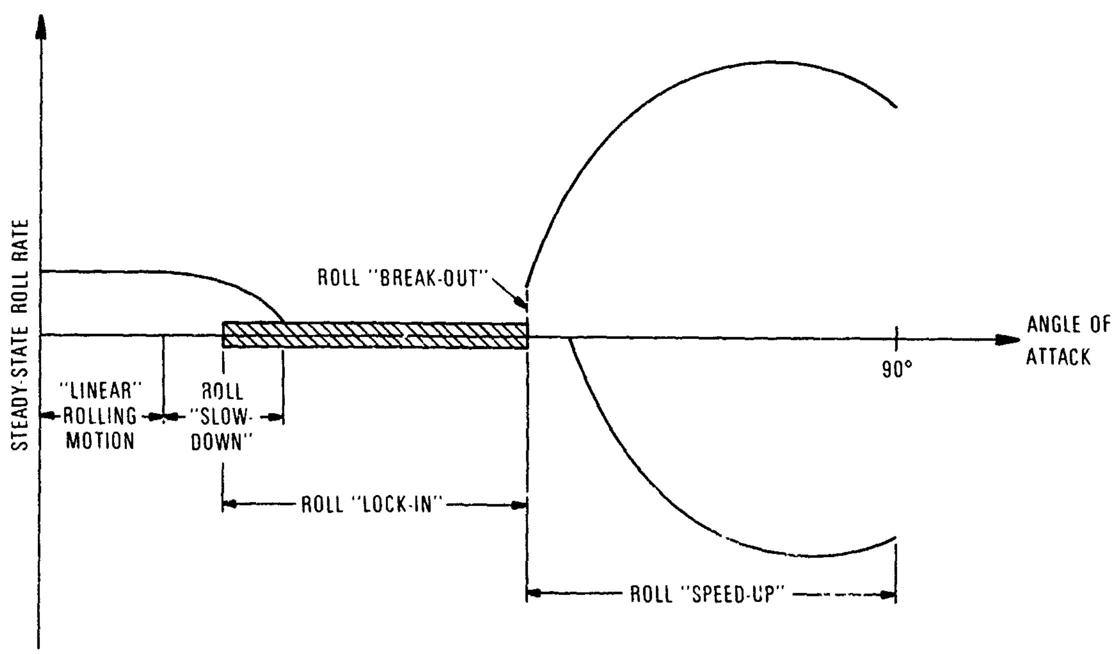

Figure 1. Characteristic Rolling Motion of a Cruciform-Finned (Body Plus Tail) Missile

The "linear" rolling motion occurs at small angles of attack. The steady-state roll rate is invariant with changes in the angle of attack in the "linear" region. The magnitude of the steady-state spin rate is proportional to the fin cant and the roll damping is considered to be a linear function of spin rate at low spin rates near the steady-state spin rate. However, at very high spin rates, the damping may be a nonlinear function of spin rate. The classical equation of rolling motion at a particular angle of attack in the "linear" region is:

$$\frac{I_x \dot{p}}{QSd} = C_{\ell_\delta}(\alpha)\,\delta + C_{\ell_p}(\alpha)\,\frac{pd}{2V}. \tag{1}$$

Equation (1) is considered adequate to describe the rolling motion in the "linear" region at low spin rates.

As the angle of attack is increased from the "linear" region where the steady-state roll rate is independent of the angle of attack, the steady-state spin rate decreases. The "slow-down" in the steady-state spin rate is caused because the ratio of the fin cant moment to the roll damping moment is decreased. The decrease in this ratio may be due to a loss in fin cant moment effectiveness due to the angle of attack or an increase in the roll damping moment due to the angle of attack or both. The classical equation of rolling motion, Equation (1), is still adequate to describe the rolling motion at angles of attack in the roll "slow-down" region. As mentioned before, at high spin rates the damping may be a nonlinear function of spin rate.

As the angle of attack increases from the roll "slow-down" region, roll "lock-in" occurs. Roll "lock-in" is characterized by oscillatory rolling motion about a roll trim angle. The amplitude of the oscillatory motion is less than ± 45 deg from the roll trim angle. The amplitude may damp at the lower angles of attack in the "lock-in" region. At higher angles of attack within the "lock-in" region, the amplitude of roll oscillations may be constant. Depending upon the initial roll conditions, a missile with fin cant at a particular angle of attack within the "lock-in" region may exhibit a non-zero, steady-state spin rate as well as "lock-in." Nicolaides showed in Reference 3 that the induced rolling moment, which varies as a function of missile angle of attack and roll orientation, causes the oscillatory rolling motion. The induced roll moment coefficient for a cruciform missile at a particular angle of attack was defined as:

$$C_\ell(\gamma) = C_{\ell(4\gamma)}(\alpha)\ \sin 4\gamma. \tag{2}$$

However, Daniels in Reference 4 found that the induced roll moment coefficient was better described by the Fourier sine series;

$$C_{\ell}(\gamma) = \sum_{k=1}^{\infty} C_{\ell(4k\gamma)}(\alpha) \sin 4k\gamma. \qquad (3)$$

Equation (3) with higher-order terms was adequate to describe the induced rolling moment at angles of attack from 0 deg up to 90 deg. The amplitude of the induced roll moment generally increases with the angle of attack. For "lock-in" to occur, the induced roll moment must balance the fin cant moment. The roll angle at which this balance occurs is the roll trim angle. The roll trim angle varies with the angle of attack because of variation in the induced rolling moment and the fin cant moment. In the "lock-in" region the roll oscillations are dynamically stable; however, as the angle of attack is increased, the roll oscillation becomes unstable and the amplitude of the oscillations grows about a roll trim angle until the missile "breaks-out" and rolls at a steady-state rate. The region where the oscillations are dynamically unstable and the steady-state rates are high is referred to as roll "speed-up." Figure 1 shows that at low angles of attack within the roll "speed-up" region, roll "break-out" occurs only in the spin direction of the fin cant. At higher angles of attack, the roll "break-out" occurs in both the positive and negative spin directions; however, the roll "speed-up" steady-state rates are higher in the direction of the fin cant. If a missile does not have fin cant, then the missile "breaks-out" in both positive and negative directions at the same angle of attack and the steady-state roll rates in the roll "speed-up" region are equal. Daniels showed in Reference 4 that the motion in the roll "speed-up" region could be explained by using a roll damping torque that is a cubic function of spin rate. Figure 2 shows that undamping (positive damping) occurs at spin rates less than the steady-state spin rate so the missile "breaks-out" and "speeds-up" to the steady-state spin rate. If the missile is forced to spin at rates above the steady-state rate where the roll damping is negative, then the missile will slow down to the steady-state spin rate. Daniels (Reference 4) assumed that the damping coefficient at a particular angle of attack could be expressed as a Taylor series whose coefficients depend on the odd powers of spin rate;

$$C_{\ell}(p) = \sum_{j}^{\infty} C_{\ell_{p^j}}(\alpha) \left(\frac{pd}{2V}\right)^{j}, \qquad (4)$$

where $j = 1,3,5,\ldots,\infty$.

Using superposition of forces (Reference 3), the fin cant moment, Fourier series for the induced moment, and the Taylor series for roll damping are combined into a more general differential equation,

$$\frac{\gamma I_x}{QSd} = C_{\ell_\delta}(\alpha)\delta + \sum_{jk} C_{\ell_{jk}}(\alpha)\dot{\gamma}^j \sin(4k\gamma + 1/2 j\pi). \qquad (5)*$$

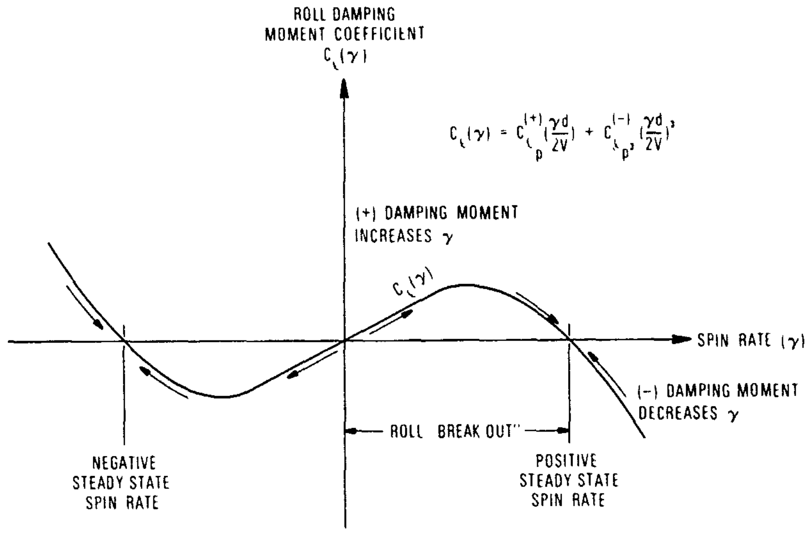

Figure 2. Roll Damping Moment Coefficient in the Roll "Speed-Up" Region

Equation (5) describes the rolling motion of a cruciform-finned missile at angles of attack from 0 through 90 deg. It is important to note that true steady-state spin rates exist only at 0 deg or very small angles of attack where the induced moment is negligible. At higher angles of attack, the roll rates approach quasi-steady-state roll rates because the induced roll moment is periodic.

Cohen and Clare in Reference 1 modified Equation (5) so that it could be incorporated into a computer program which uses the "global" nonlinear least-squares procedures to extract roll moment coefficients.

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* Equation (5) is due to Dr. C. J. Cohen, Research Associate for the Warfare Analysis Department, Naval Surface Weapons Center, Dahlgren Laboratory, Dahlgren, Virginia.

Cohen, Clare, and Stevens in Reference 5 then modified the differential equation to include mass and/or aerodynamic asymmetry terms. The modified equation became:

$$\ddot{\gamma} = \underset{\sim}{Q} \sum_{j=0}^{J} \left(\frac{\dot{\gamma} d}{2V}\right)^{j} \sum_{k=0}^{K} \left(C_{jk} \cos 4k\gamma + S_{jk} \sin 4k\gamma\right) \tag{6}$$

$$+ C_{ac} \cos \gamma + C_{as} \sin \gamma$$

$$\gamma(0) = \gamma_0 \qquad \dot{\gamma}_{(0)} = \dot{\gamma}_0$$

The correspondence between the aerodynamic coefficients in Equation (6) (C_{jk} and S_{jk}) and more conventional nomenclature used in Equation (5) is shown in Table 1.

Table 1. Aerodynamic Roll Moment Coefficient Correlation*

Coefficient: Conventional Nomenclature	Coefficient: Computer Program Nomenclature	Description
$C_{\ell_\delta}\delta$	C_{00}	Fin cant roll moment coefficient
$C_{\ell_{\delta(4\gamma)}}\delta$	C_{01}	Variation of fin cant moment Coefficient with roll angle
$C_{\ell_{\delta(8\gamma)}}\delta$	C_{02}	
$C_{\ell_{\delta(12\gamma)}}\delta$	C_{03}	
$\vdots$	$\vdots$	
$C_{\ell_{\delta(4K\gamma)}}\delta$	C_{0K}	

*All coefficients are a function of the missile's angle of attack.

Table 1. Aerodynamics Roll Moment Coefficient Correlation* (Continued)

Coefficient: Conventional Nomenclature	Coefficient: Computer Program Nomenclature	Description
C_{ℓ_p}	C_{10}	Linear roll damping moment coefficient
$C_{\ell_{p^2}}$	C_{20}	Quadratic roll damping moment coefficient
$C_{\ell_{p^3}}$	C_{30}	Cubic roll damping moment coefficient
$\vdots$	$\vdots$	
$C_{\ell_{p^J}}$	C_{J0}	J^{th} order roll damping moment coefficient
$C_{\ell_{p(4\gamma)}}$	C_{11}	Variation of linear roll damping Moment coefficient with roll Angle
$C_{\ell_{p(8\gamma)}}$	C_{12}	
$C_{\ell_{p(12\gamma)}}$	C_{13}	
$\vdots$	$\vdots$	
$C_{\ell_{p(4k\gamma)}}$	C_{1K}	
$C_{\ell(4\gamma)}$	S_{01}	Induced rolling moment coefficients
$C_{\ell(8\gamma)}$	S_{02}	
$C_{\ell(12\gamma)}$	S_{03}	
$\vdots$	$\vdots$	
$C_{\ell(4K\gamma)}$	S_{0K}	
	$C_{\alpha c}$	Roll asymmetry coefficients (Combinations of aerodynamic and mass asymmetry constants)
	$C_{\alpha s}$	

*All coefficients are a function of the missile's angle of attack.

CONFIGURATIONS AND TEST CONDITIONS

Figure 3 shows a sketch of the basic missile configuration used in this test. This configuration was recommended by NWC.

The three-inch model used in this test had canards and tail fins with planar cross sections and rounded leading edges. The model was designed so that body build-up configurations (body plus canards, body plus tail, and body plus canard plus tail) could be tested. The body build-up configurations were tested to determine the contribution of the canards, tails, and canard-tail interference to the roll damping torque. The individual canards were adjusted to fixed deflection angles during testing. Five different canard deflection patterns were selected to approximate missile canard deflections during different maneuvers. The patterns chosen included 0-deg deflection and deflections to provide roll torque, pitch control, roll torque with pitch, and off-axis pitch control. Two sets of tail fins provided 0- and 5-deg fin cant roll torque. Table 2 gives the canard and tail fin deflection used on each of the 17 body build-up configurations. Figure 3 shows the canard-control missile configuration dimensions. The nomenclature and sign convention for the canard and tail deflections is shown in Figure 4. The model was mounted on a free-rolling air bearing which had negligible friction eliminating bearing friction force in the analysis of the test data.

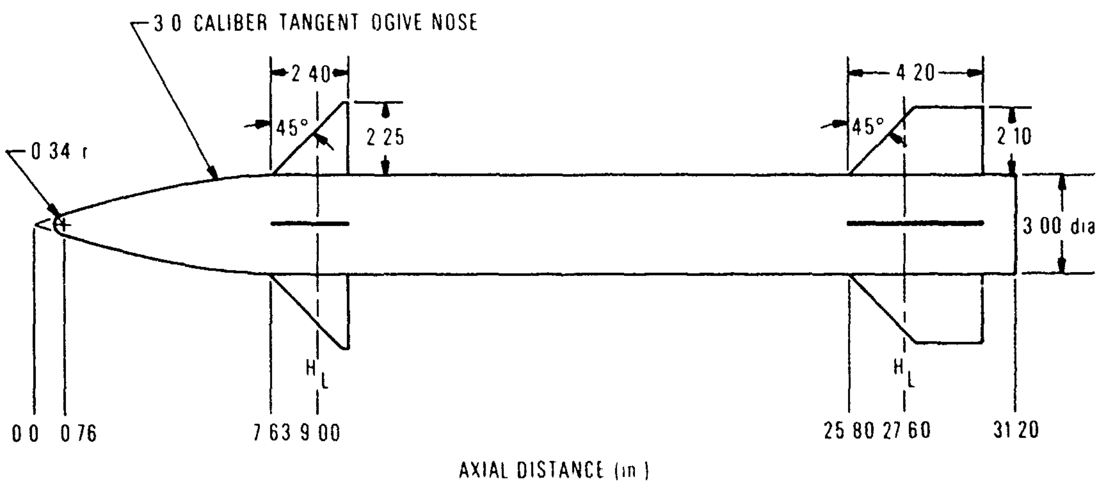

Figure 3. Canard-Control Missile Configuration Dimensions (Body Plus Canard Plus Tail)

Table 2. Configuration Fin Deflections

Configuration	Deflections (deg) Canards C1	C2	C3	C4	Tail T1	T2	T3	T4
Body plus Tail	-	-	-	-	0	0	0	0
	-	-	-	-	5	5	5	5
Body plus Canard Zero Deflection	0	0	0	0	-	-	-	-
(Differential Canard Cant)	10	0	10	0	-	-	-	-
(Pitch Control with Differential Canard Cant)	10	15	10	-15	-	-	-	-
(Pitch Control Only)	0	15	0	-15	-	-	-	-
(Off-Axis Pitch Control)	15	15	-15	-15	-	-	-	-
Body plus Canard plus Tail	0	0	0	0	0	0	0	0
	10	0	10	0	0	0	0	0
	10	15	10	-15	0	0	0	0
	0	15	0	-15	0	0	0	0
	15	15	-15	-15	0	0	0	0
	0	0	0	0	5	5	5	5
	10	0	10	0	5	5	5	5
	10	15	10	-15	5	5	5	5
	0	15	0	-15	5	5	5	5
	15	15	-15	-15	5	5	5	5

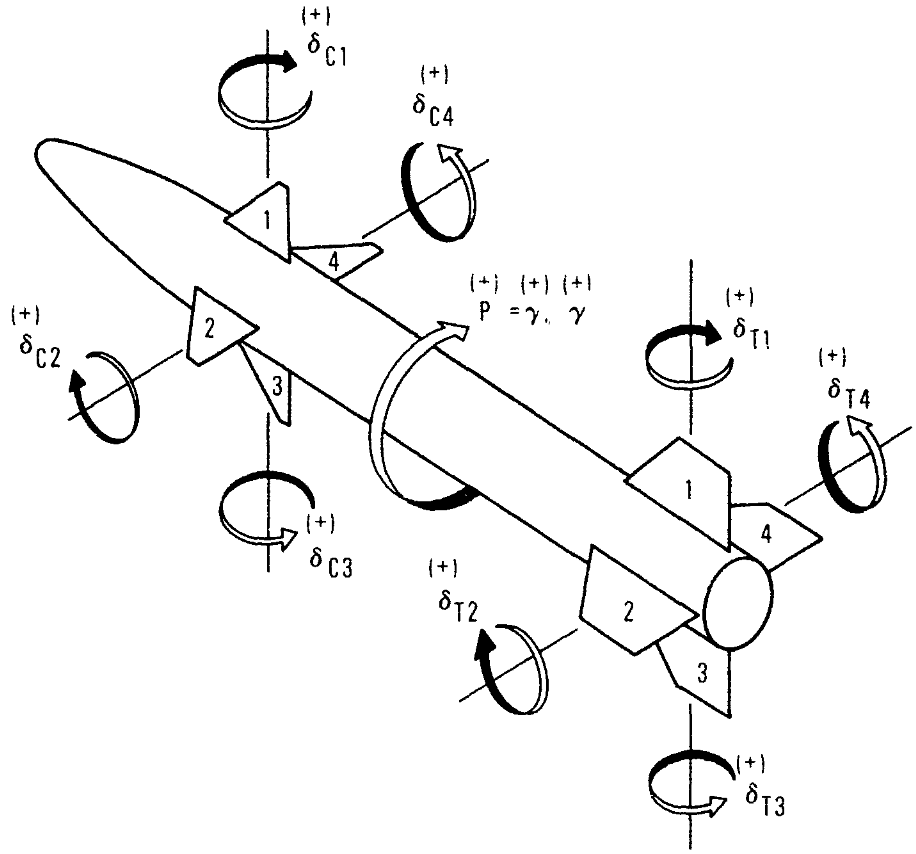

Figure 4. Nomenclature and Sign Conventions for Canard and Tail Deflections

The tests were conducted in the 7 x 10 ft low-speed wind tunnel of the Army Air Mobility Research and Development Laboratory, Moffet Field, California. The air bearing that supported the model was mounted on a general purpose sting. Although the sting was capable of providing combinations of pitch, yaw, and roll angles, the sting was programmed to provide only yaw in the horizontal plane. The yaw angle is the total angle of attack; therefore, no distinction is made between them. Each configuration was tested at angles of attack from 0 through 30 deg in 5-deg increments. The angle of attack was fixed during each data run.

The rolling motion of the model was recorded using a high-speed movie camera. The camera was equipped with a timing generator which provided precise timing marks on the film records at the rate of ten marks per second. The lens of the camera was mounted on a flexible fiber optics cable so that the centerline of the lens could be mounted closer to the model's axis of rotation. The fiber optics cable also allowed the camera to be moved further downstream from the model. The trailing edges of the canards and tail fins were coded so that the roll orientation of the model could be determined from the movie film. The film provided roll orientation versus time data. The lens and movie camera were mounted on the sting so that they moved in pure yaw, always pointing parallel to the model's roll axis. A photograph of the test equipment is shown in Figure 5.

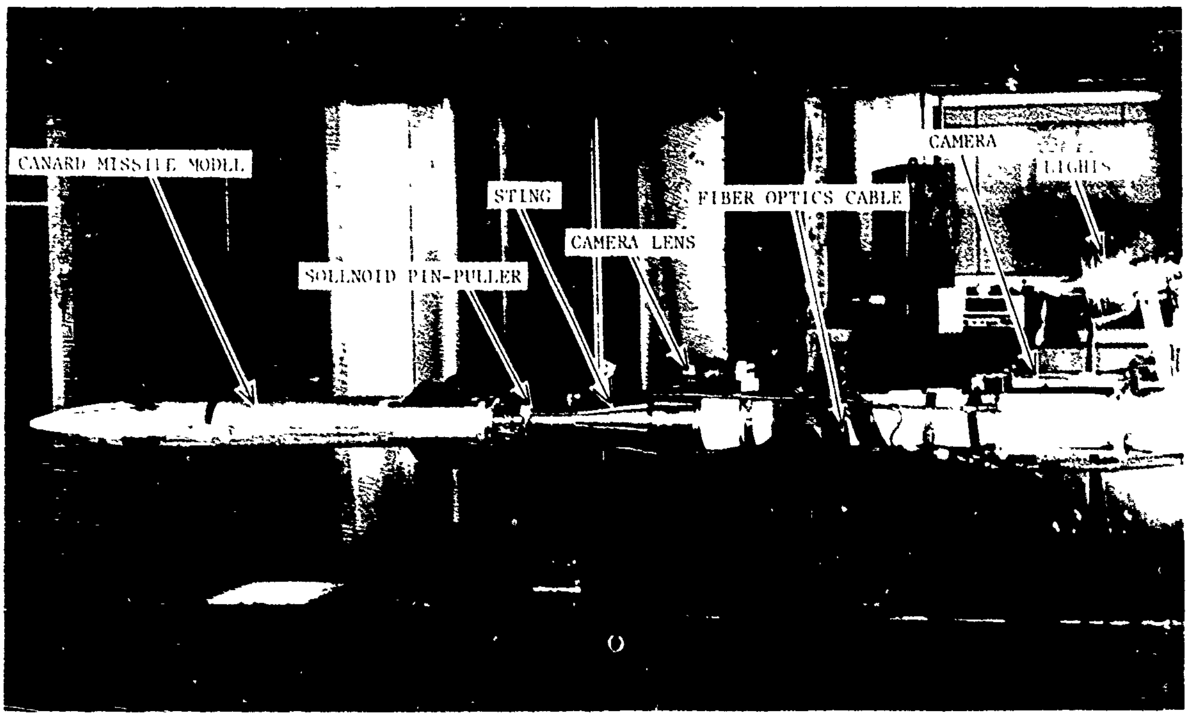

Figure 5. Wind Tunnel Model in Army Air Mobility Research and Development Laboratory's 7 x 10 ft Wind Tunnel

To obtain proper rolling motion, the initial conditions of the missile must be controlled. A solenoid-actuated pin at the base of the missile locked the missile at a fixed roll angle until the wind tunnel test conditions had stabilized. At the beginning of a test run, the pin was pulled, unlocking the model to roll freely. In other runs, the missile was spun-up to a high spin rate at the beginning of the test. An external jet of air was created by a nozzle on the end of a long pressurized pipe. The pipe, referred to as a wand, was used to position the air jet so that it blew against the model's fins spinning the model up. When the model reached adequate spin rates, the wand was withdrawn from the flow field in the wind tunnel, thus, beginning the run. The wand was used (with the air jet cut off) to manipulate the model to find roll "lock-in" phenomena.

The wind tunnel was operated at a dynamic pressure (Q) of approximately 15 psf (718.2 Pa) due to the load limitations of the air bearing. The nominal velocity of the tests was about 113 ft/s (34.44 m/s). The exact flow conditions in the tunnel at the time of each data run were recorded by an auxiliary computer.

The initial conditions of each run depended on the configuration and the type of motion the configuration exhibited at the particular angle of attack of the run. Configurations with tail fin cant and/or canard cant that exhibited steady-state roll rates used the solenoid pin to hold the model at γ_0 = 0-deg roll orientation until the tunnel was stabilized at the test conditions. Then the camera was turned on and the pin was pulled. The camera photographed the missile as it spun-up to a steady-state rate. If oscillatory motion was observed, then various roll orientations were used as initial conditions to explore the rolling motion for dual modes, "lock-in," and roll oscillations. Roll oscillations were needed to extract the induced roll moment coefficients. If a configuration did not exhibit a steady-state roll rate, then the model was spun-up using the air jet on the wand. When the tunnel was running at test conditions and the model was spun-up to an adequate rate, the wand was withdrawn from the wind tunnel just before the camera was turned on. The camera was not stopped until the motion of the missile stopped or the motion reached a quasi-steady-state rate.

Appendix A contains a run log for the wind tunnel test. The log includes configuration canard and tail deflections, tunnel flow conditions, angle of attack, initial conditions, and remarks about the rolling motion of configuration for each run.

DISCUSSION OF WIND TUNNEL DATA

The results of the wind tunnel tests included approximately 350 data runs that were recorded by high-speed movie film and a run log documenting test conditions for these runs. Repeat runs were conducted and are included in the 350 runs. The film data were reduced to roll orientation versus frame number by digitizing the roll angle on each frame. Timing marks were also read so that the frame number could be converted into time. Because of funding limitations, only seven data runs were digitized and analyzed. The body plus canard plus tail configuration with 0-deg control deflections was selected for analysis because it is a complete, simple, symmetric configuration which is more amenable to theoretical analysis. Figures 6 through 12 show the roll orientation versus frame number for the configuration, covering the angle-of-attack range from 0 to 30 deg. The roll orientation angle is shown on a scale from 0 to 360 deg to produce a useful size graph.

Since this configuration did not possess intentional fin cant, the missile was spun-up and then allowed to damp at each angle of attack. At angles of attack 0 and 5 deg, the missile damped to a small steady-state rate due to some unintentional asymmetry which produced a small roll torque. The consistent decay of spin rate to a small steady-state spin rate is predicted by linear theory (Equation (1)). At angles of attack from 10 to 25 deg, the missile's spin rate decays until the missile exhibits damped roll oscillation about a roll trim angle (lock-in). The fluctuation in the spin rate every 90 deg and the preferred roll orientation indicate the presence of the induced roll moment. The motion is similar to the rolling motion that the cruciform body-tail missile exhibited in the "lock-in" region. The frequency of the roll oscillations indicates that the induced roll moment increases with increasing angles of attack. At a 30-deg angle of attack, the missile spin rate decays until oscillatory motion begins; however, the oscillatory motion does not damp. This motion is neither roll "lock-in" nor "speed-up." Similar motion was observed and documented for the cruciform body-tail missile in Reference 6. Thus, it appears that the motion of the body plus canard plus tail configuration with 0-deg deflection is similar to the motion exhibited by a cruciform body plus tail configuration. For this reason, Equation (6) was used as the equation of motion for the canard missile configuration in the procedure to extract the nonlinear roll moment coefficients.

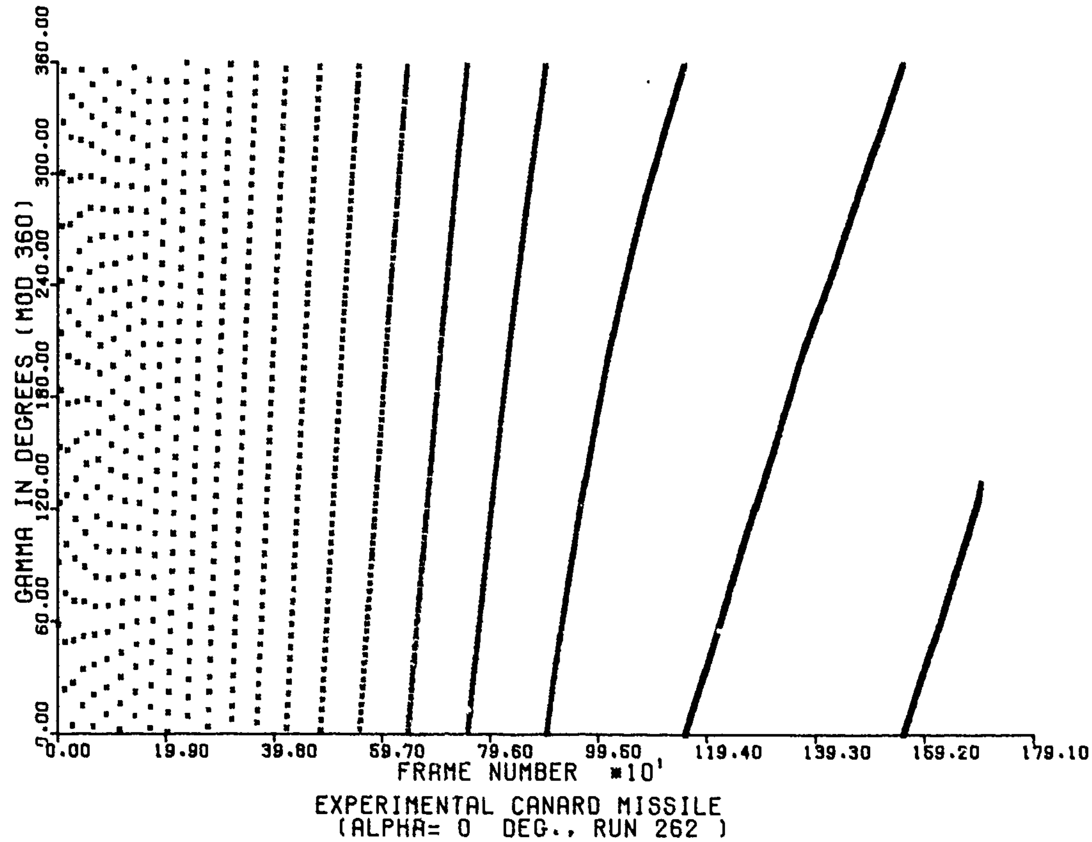

Figure 6. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 0-deg Angle of Attack

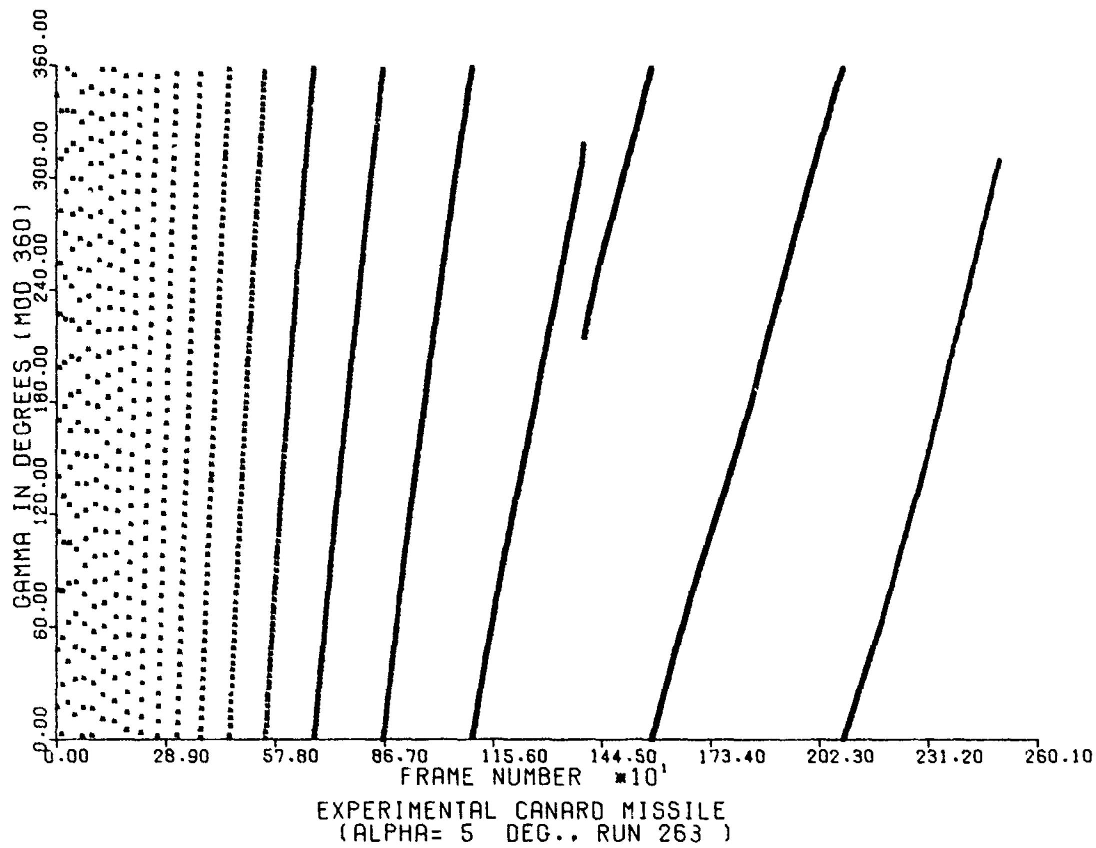

Figure 7. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 5-deg Angle of Attack

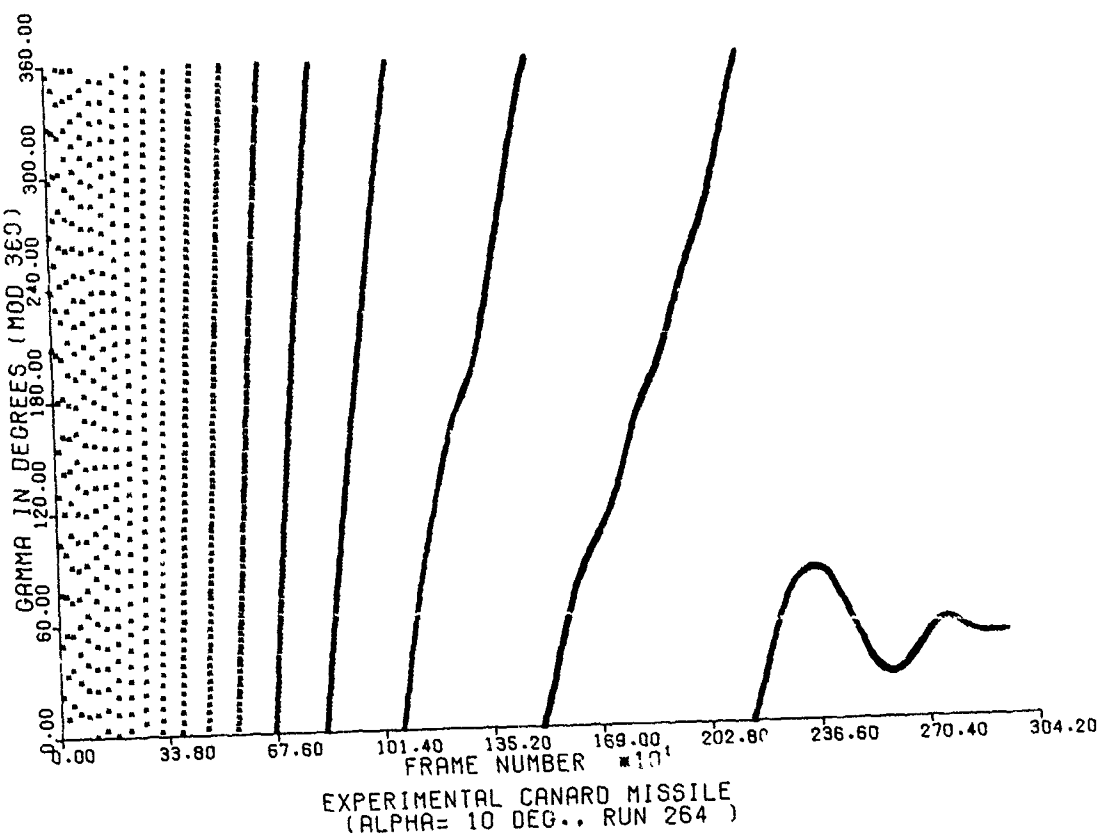

Figure 8. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 10-deg Angle of Attack

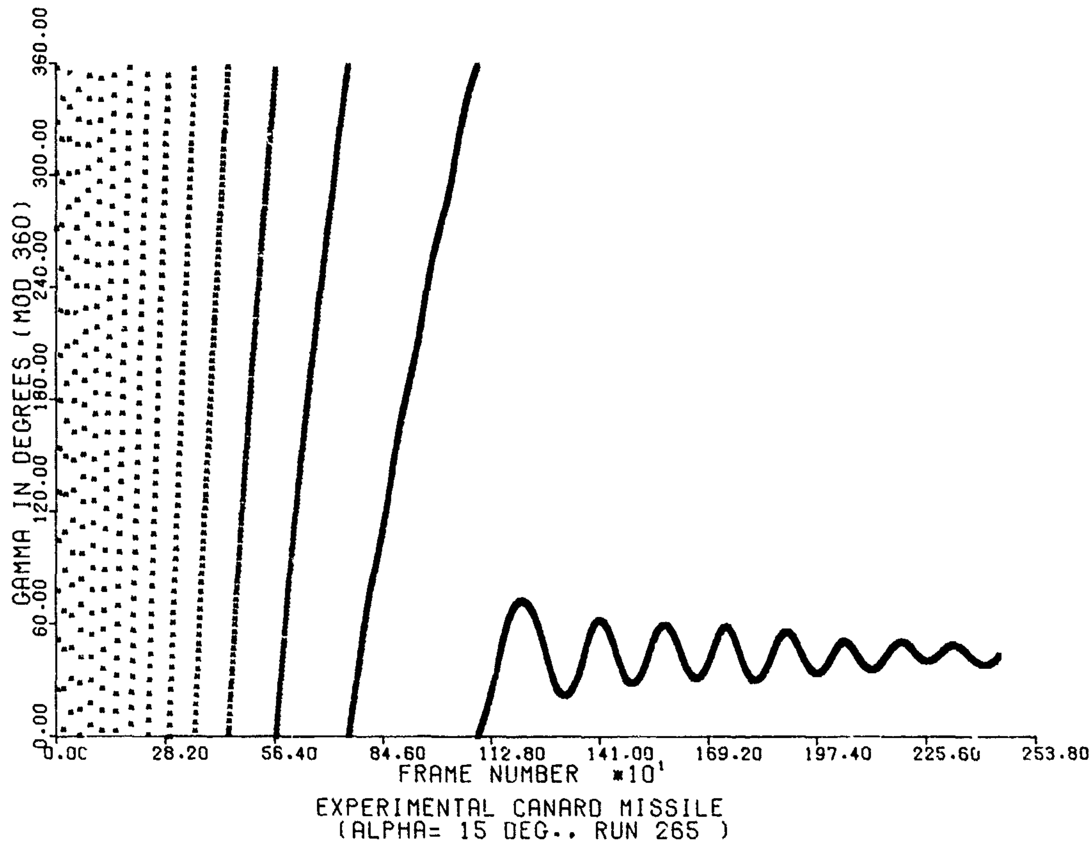

Figure 9. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 15-deg Angle of Attack

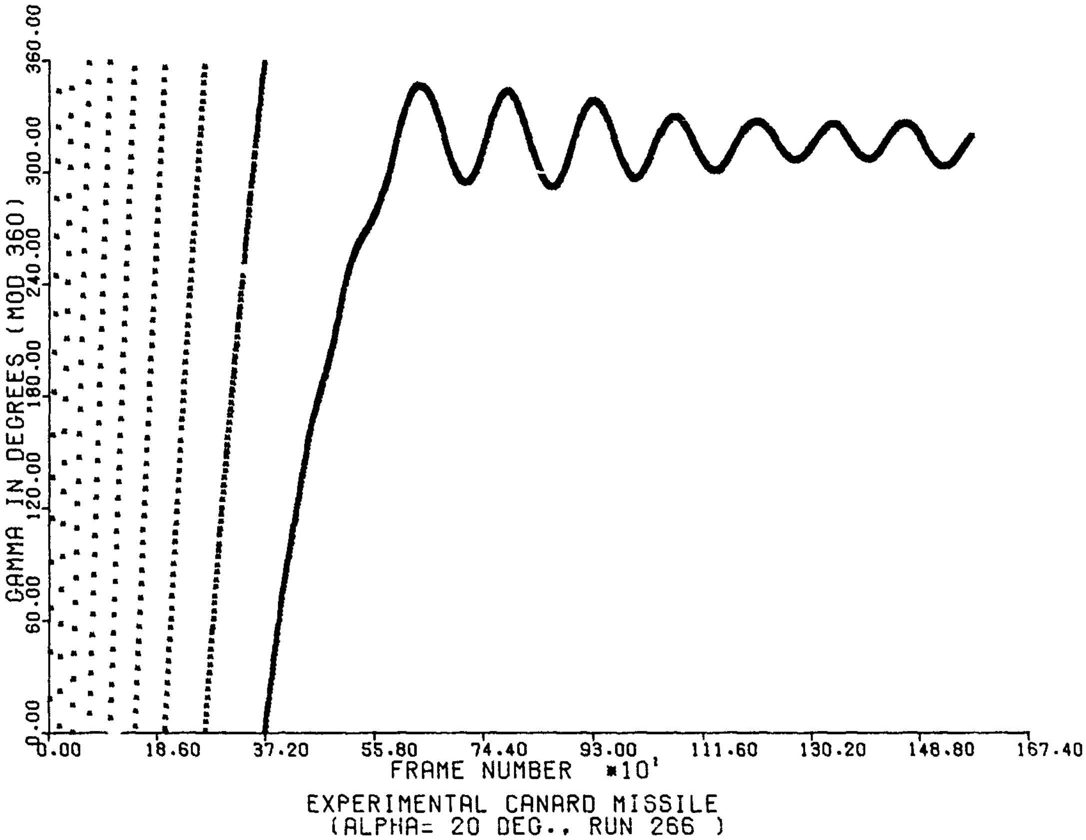

Figure 10. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 20-deg Angle of Attack

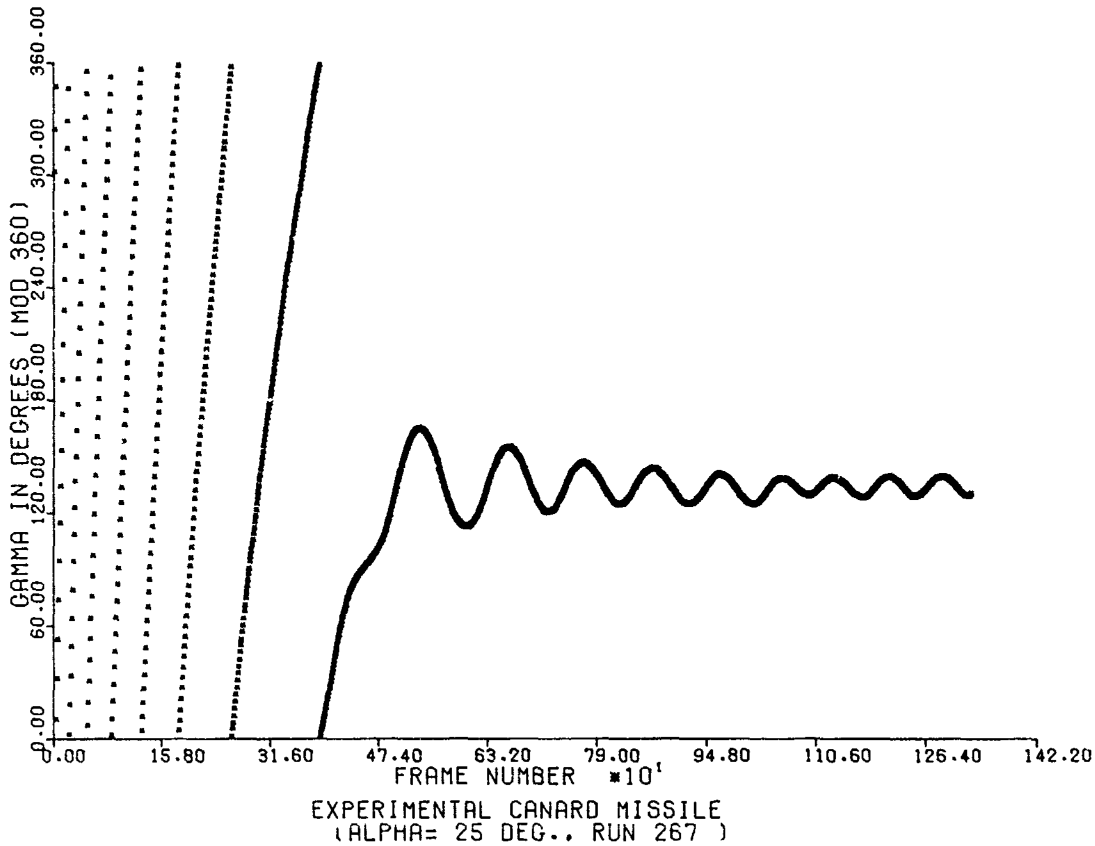

Figure 11. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 25-deg Angle of Attack

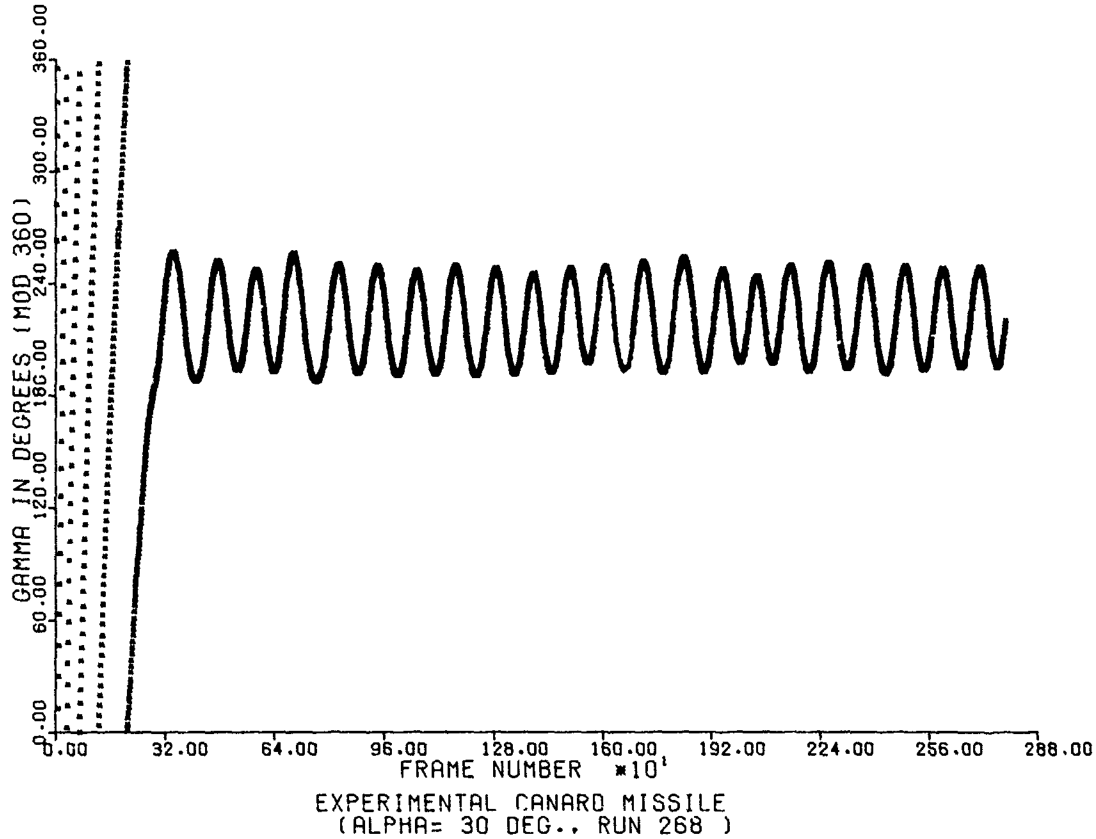

Figure 12. Observed Roll Angle Versus Frame Number for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 30-deg Angle of Attack

ROLL MOMENT COEFFICIENT EXTRACTION

The "global" nonlinear least-squares procedure fits the roll equation of motion (Equation (6)) to segmented observed rolling motion data. The fitting process requires the variation of the sum of the squares of the residuals (between observed and computed roll angles) with respect to perturbed coefficients to vanish. The coefficients are incremented in an iterative fashion until the sum of the squares of the residuals converge. The observed data was divided into segments. The segment size was made as large as possible, but small enough to allow convergence during both "local" and "global" fitting. Equation (6) is fit "locally" to each of the observed data segments using constant best estimate roll moment coefficients to determine initial conditions (roll angle and roll rate) for that segment. The initial conditions are determined for each segment independent of the other segments. All of the observed data segments are fit "globally" to obtain a new set of roll moment coefficients and new initial conditions for each segment. Discontinuities or jumps occur in the computed roll rate and roll angle between the segments. The jumps are needed because the sum of the square of the residuals may become too large for convergence when the data is fit over a long time period. The large residuals may be due to truncation of the equation of motion, unmodeled turbulence, or other unmodeled transients in the wind tunnel. The jump in roll angle and roll rate due to independent initial conditions of a segment allow a restart of the motion in regions where the rolling motion is sensitive to accumulated error of roll angle and roll rate. Estimates of the fin cant moment coefficient, linear roll damping, and induced roll moment coefficient were used to begin the fitting process. Estimates of the initial roll angle and roll rate for each segment were estimated from the observed data. Once a fit was obtained, additional coefficients were included until all of the desired coefficients were obtained or until the fitting procedure would not converge. Then the segments were made as long as possible while allowing convergence. Large segments were desired so that the inaccuracy in the aerodynamic coefficients due to the jumps in the segments' initial condition would be minimized. These techniques were applied to each data run until a set of roll moment coefficients were obtained at each angle of attack.

The method and equations employed in the "global" nonlinear least-squares fitting procedure are contained in detail in References 1 and 5. Description of the computer program utilizing the fitting technique to extract the roll moment coefficients is presented in Reference 7.

DISCUSSION OF RESULTS

Five aerodynamic coefficients were considered in fitting the seven data runs of the body plus canard plus tail configuration with 0-deg deflections. The coefficients included fin cant, linear damping, induced roll moment, and the roll asymmetry terms. Two additional higher order, induced roll moment coefficients were extracted from the run at 30-deg angle of attack because of the oscillatory data in that run. Five coefficients were thought to be adequate to describe the motion exhibited in the data runs. Higher order roll damping coefficients were not extracted since these coefficients are usually determined from roll "speed-up" data. Figures 13 through 19 show comparison plots of the observed and computed roll angle data for the seven angles of attack. Comparison of Figures 6 through 12 and Figures 13 through 19, respectively, shows the correlation between frame number and time. The computed curves were calculated using the extracted coefficients. The small lines drawn normal to the computed curves indicate segment locations. The plots show that there is good agreement between the observed and computed roll angles considering the small number of segments used. In Figure 14, a portion of data is missing due to a camera malfunction; however, the results are not significantly affected since the data were segmented around the gap in the data. Better fits could have been obtained in Figures 17 and 18 by adding higher order induced and damping terms (e.g., S_{02}, S_{03}, C_{11}, C_{12}).

Figure 20 presents a comparison plot of the extracted and predicted linear roll damping coefficients as functions of angle of attack. The predicted roll damping coefficient values were taken from Reference 8. The experimental and predicted values compare favorably at all angles of attack except 30 deg. A decrease in roll damping would be expected since the roll damping of a cruciform body plus tail missile becomes positive in the roll "speed-up" region. The roll "speed-up" region may begin at a 45-deg angle of attack in some cruciform body plus tail configurations. Amplitudes of the oscillatory motion in Figure 19, also, indicate that the damping is nearly zero.

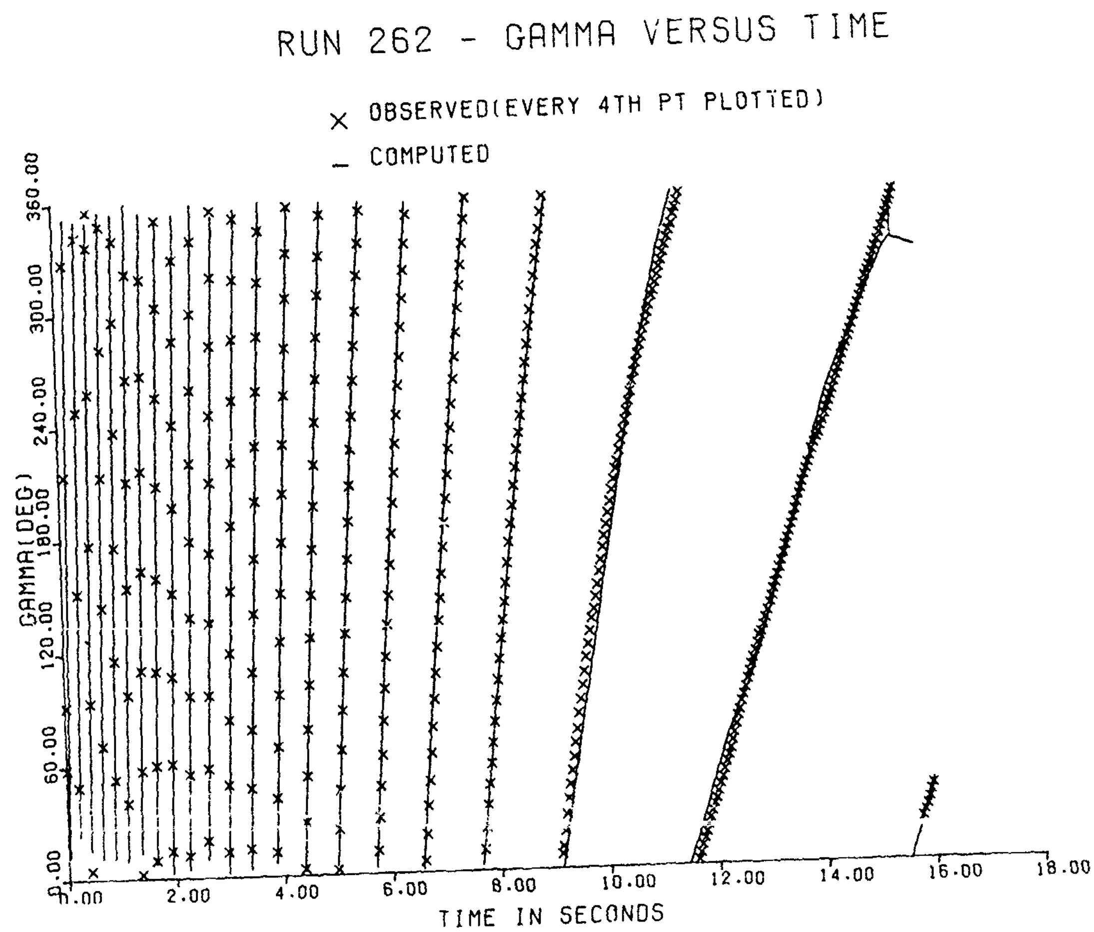

Figure 13. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 0-deg Angle of Attack

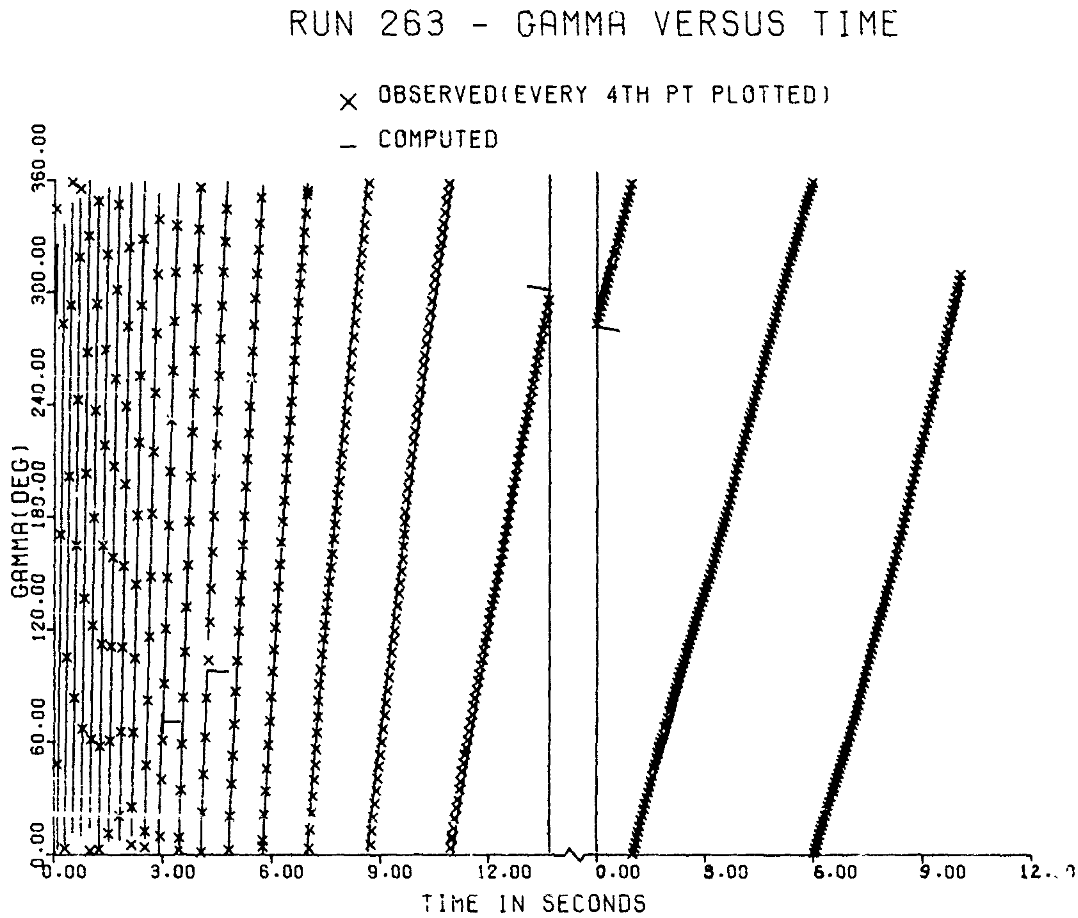

Figure 14. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 5-deg Angle of Attack

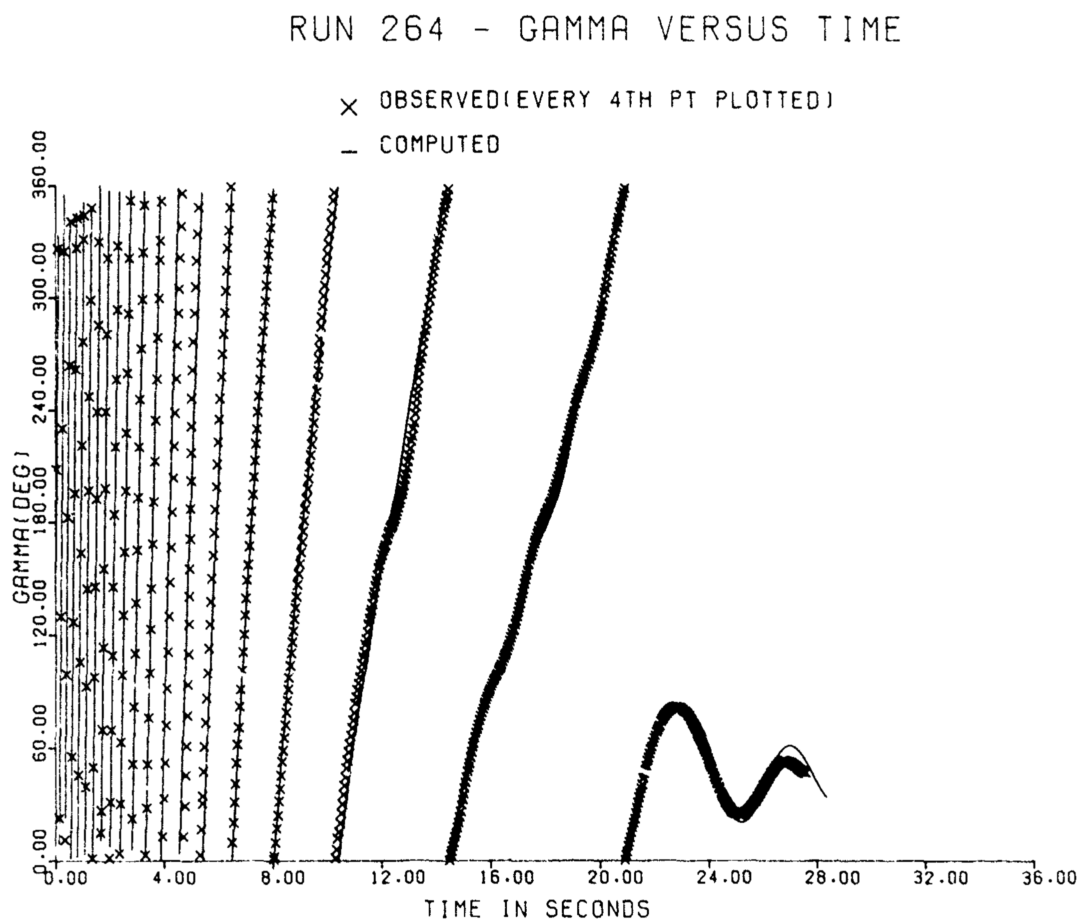

Figure 15. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 10-deg Angle of Attack

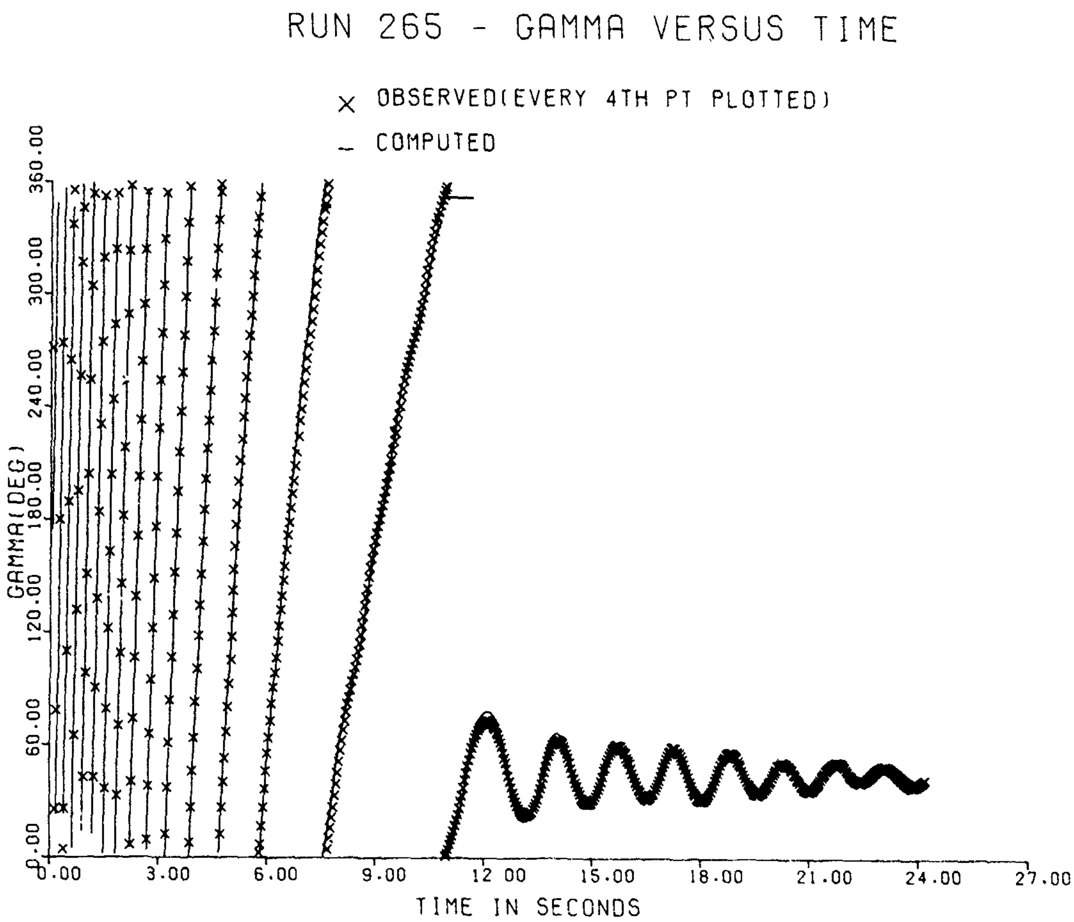

Figure 16. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 15-deg Angle of Attack

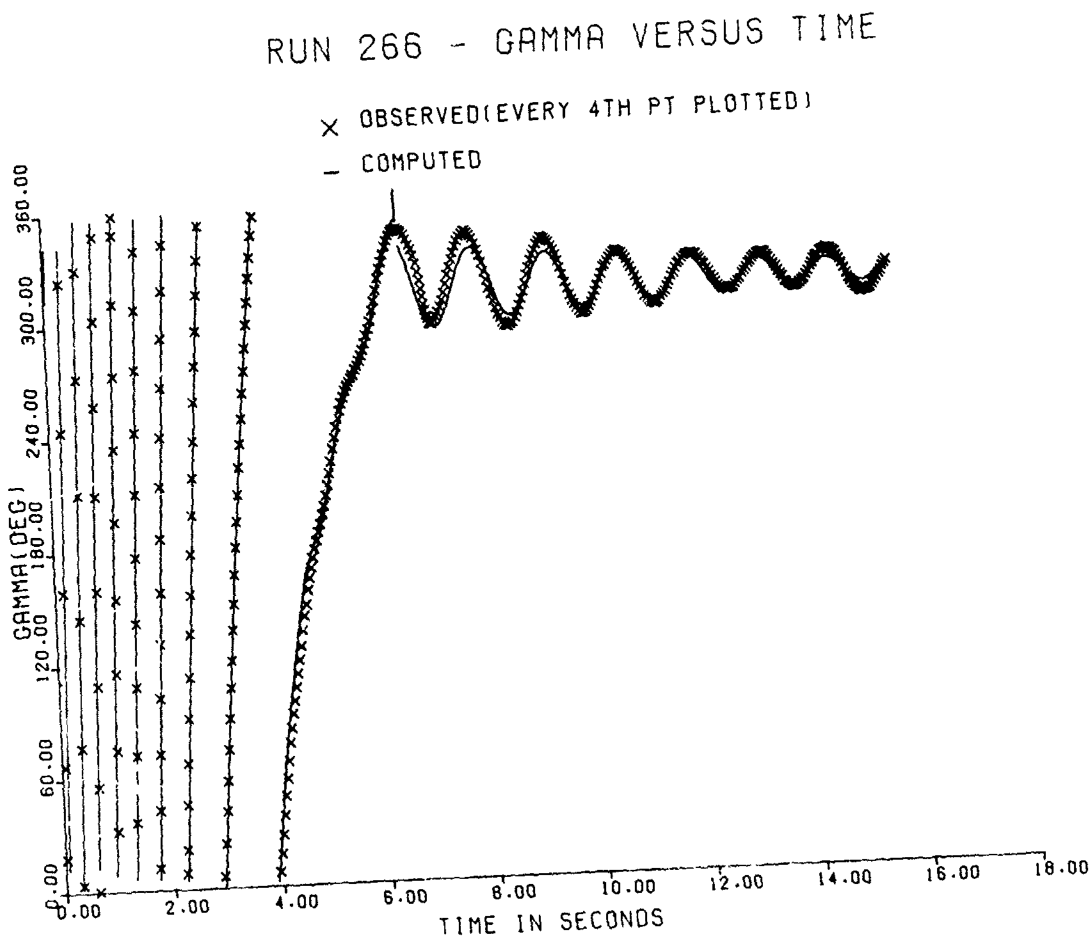

Figure 17. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 20-deg Angle of Attack

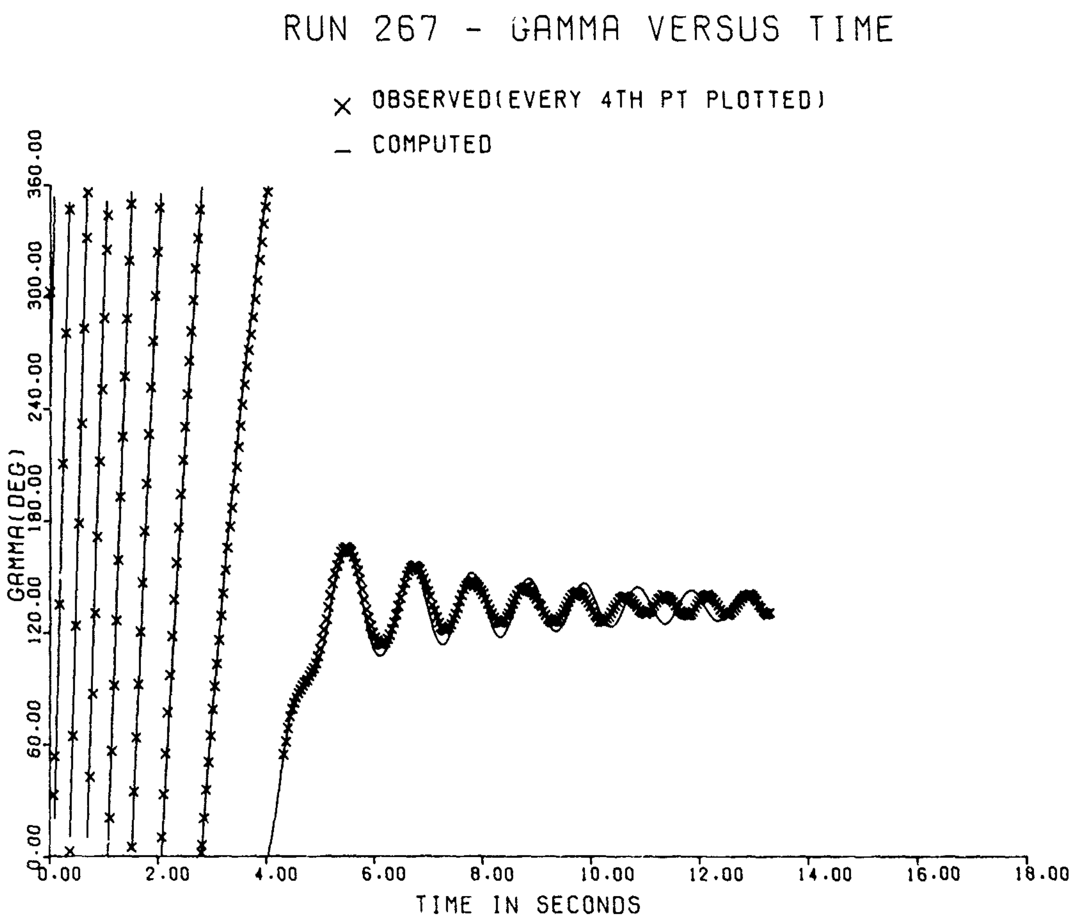

Figure 18. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 25-deg Angle of Attack

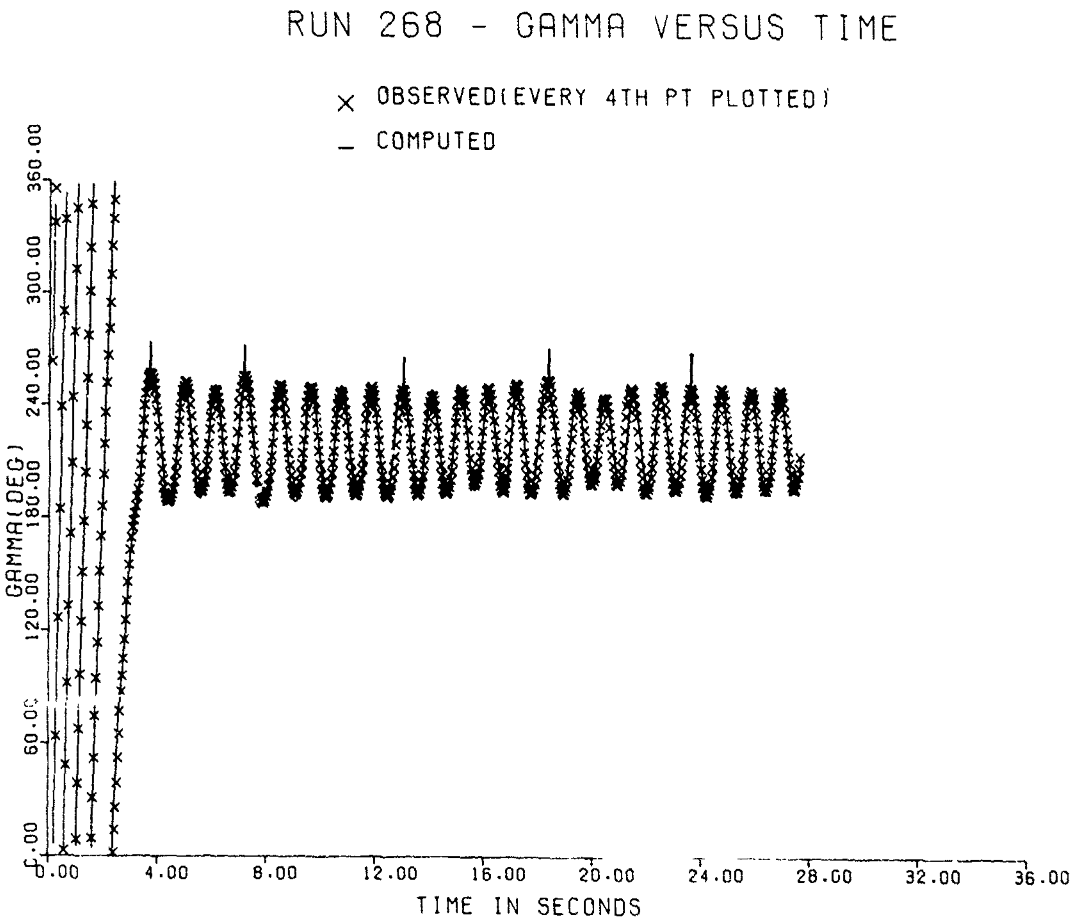

Figure 19. Comparison of Observed and Computed Roll Angles for Body Plus Canard Plus Tail Configuration With 0-deg Deflections at 30-deg Angle of Attack

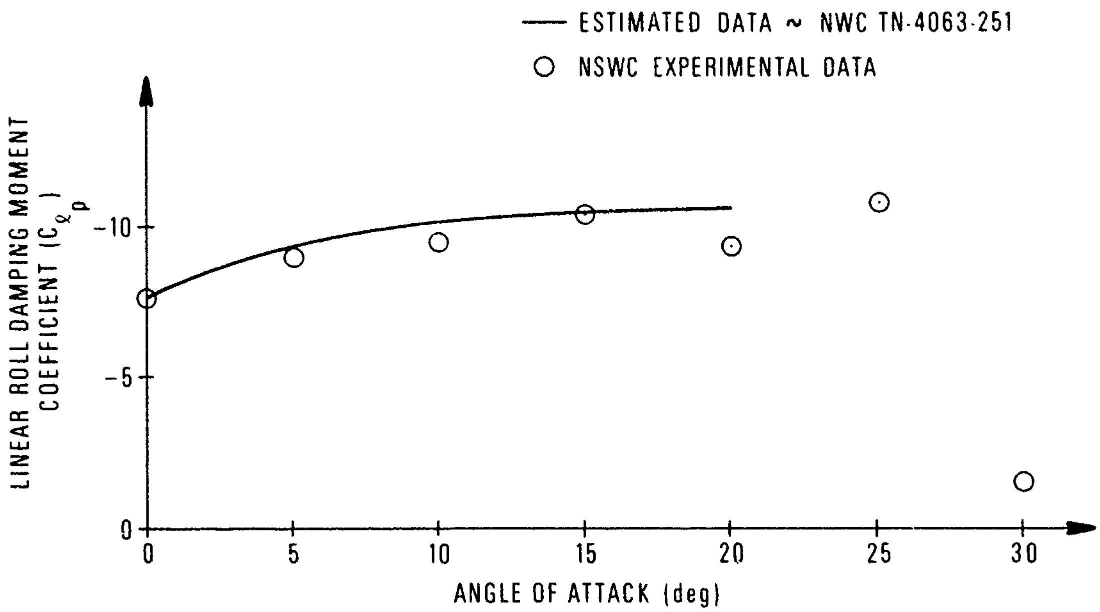

Figure 20. Comparison of Predicted and Experimental Linear Roll Damping Moment Coefficients for Body Plus Canards Plus Tail Configuration With 0-deg Deflections

The extracted fin cant moment coefficient versus angle of attack is shown in Figure 21. These results appear reasonable at angles of attack from 0 through 15 deg because a small positive roll torque was observed. The results obtained for the fin cant coefficient ($C_{\ell_\delta}\delta$) at higher angles of attack were unexpected and no explanation is presented for these results.

Figure 22 shows that the induced roll moment coefficient ($C_{\ell(4\gamma)}$) generally increases with the angle of attack. An error is present in the data point at a 0-deg angle of attack. The induced roll moment should be 0 at 0-deg angle of attack. The absence of 0-deg oscillatory type motion in the observed data at 0-deg angle of attack (shown in Figure 13) indicates that the induced roll moment is zero. The error may have occurred because there was no oscillatory data. The small negative value for the induced roll moment coefficient at a 5-deg angle of attack is expected since the cruciform body plus tail configuration in Reference 3 exhibited similar small negative values at small angles of attack.

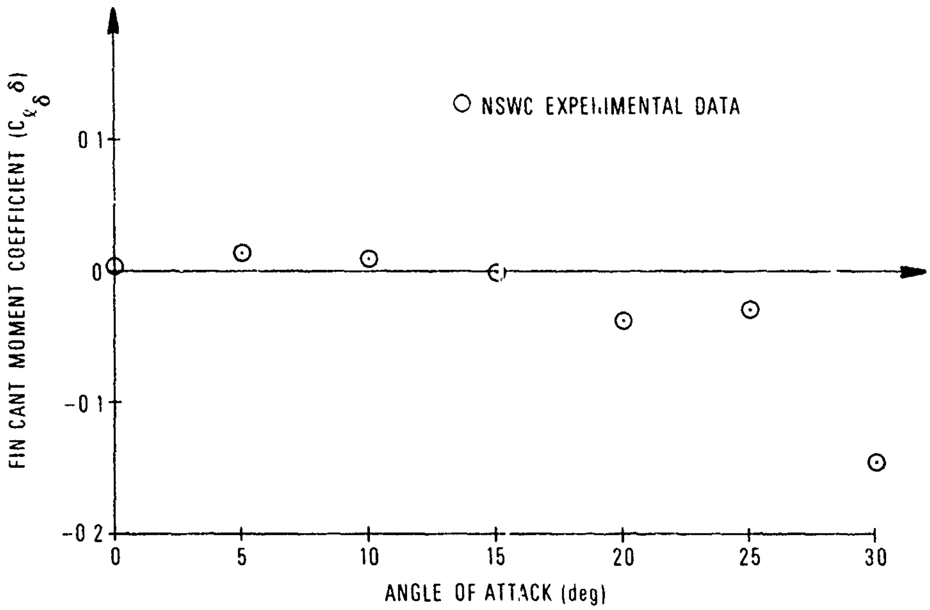

Figure 21. Experimental Fin Cant Moment Coefficients for Body Plus Canard Plus Tail Configuration with 0-deg Deflections

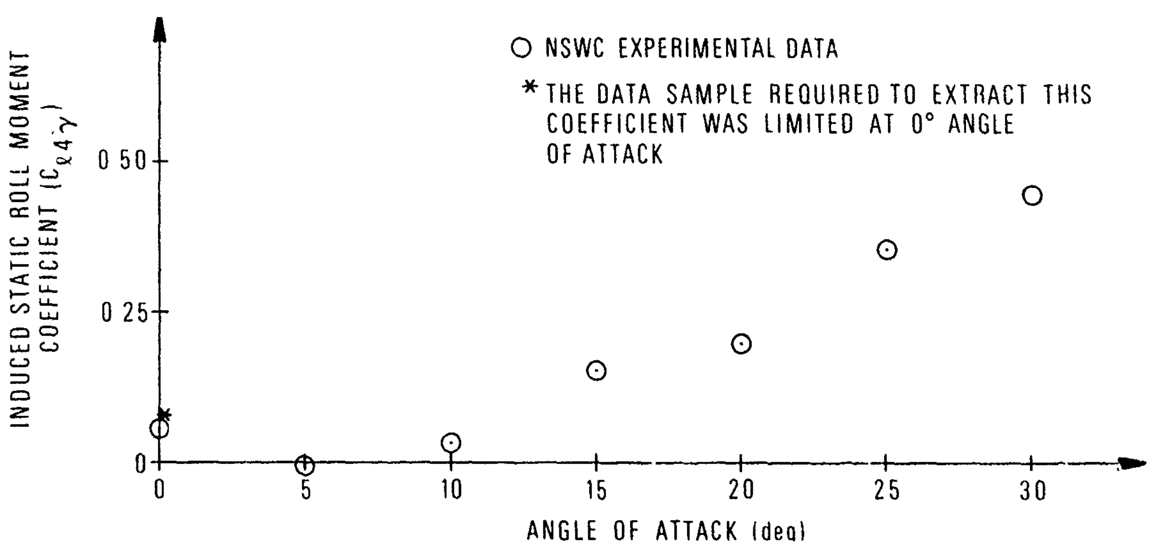

Figure 22. Experimental Induced Static Roll Moment Coefficients for Body Plus Canard Plus Tail Configuration with 0-deg Deflections

SUMMARY AND FUTURE PLANS

Subsonic free-rolling wind tunnel tests have been conducted on 17 canard missile configurations. Wind tunnel data have been reduced to roll angle versus frame number for seven data runs of the body plus canard plus tail configuration with 0-deg deflections. At least five basic coefficients were extracted from the seven data runs. The extracted coefficient results were provided to NWC. The results for the body plus canard plus tail configuration with 0-deg deflections showed that the linear roll damping moment coefficient (C_{ℓ_p}) increases slightly with angle of attack up to about 20 deg, as predicted. However, at 30 deg, the coefficient decreases significantly. The induced static roll moment ($C_{\ell(4\gamma)}$) was slightly negative at 5-deg angle of attack and increased positively with increasing angle of attack through 30 deg as expected.

In future work, body plus tail and body plus canard configurations with 0 deg deflections will be analyzed to determine canard, tail, and canard/tail interference contributions to the roll damping of a complete canard missile configuration. In addition, the body plus canard plus tail configuration with 15-deg pitch control deflections will be analyzed to determine the effect of a large pitch deflection on the missile's roll damping.

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8. Meeker, R. E., Estimation of the Damping in Roll of a Canard Cruciform Missile in Incompressible Flow, NWC Technical Note 4063-251, Naval Weapons Center, China Lake, CA, January 1976.

APPENDIX A

RUN LOG FOR SUBSONIC FREE-ROLLING WIND TUNNEL TEST OF CANARD-CONTROL MISSILE

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	CONFIGURATION: TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	INITIAL CONDITIONS: PIN-PULL ANGLE (DEG)	REMARKS
0	-	-	-	-	0	0	0	0	.0	-	-	-	-	-		Model has asymmetry Zero Frame
1	-	-	-	-	0	0	0	0	.0	15.16	522.9	113.19	2124.2	Spun-Up Wand		Air Bearing P = 40 PSI Wand Pressure = 200 PSI
2	-	-	-	-	0	0	0	0	5.0	15.16	523.3	113.23	2124.2	"		
3	-	-	-	-	0	0	0	0	10.0	14.97	523.6	112.54	2124.4	"		Weak Lock-in Begins
4	-	-	-	-	0	0	0	0	15.0	15.47	523.6	114.42	2123.9	"		Lock-in
5	-	-	-	-	0	0	0	0	20.0	15.08	524.0	113.01	2124.3	"		Lock-in
6	-	-	-	-	0	0	0	0	25.0	15.16	524.0	113.30	2124.2	"		Lock-in Strong
7	-	-	-	-	0	0	0	0	25.0	15.18	528.1	113.86	2122.7		+15	Pin Pull
8	-	-	-	-	0	0	0	0	25.0	15.14	528.4	113.75	2122.8		+30	
9	-	-	-	-	0	0	0	0	20.0	14.66	528.8	111.95	2123.2		+15	Few Oscillations
10	-	-	-	-	0	0	0	0	20.0	15.01	528.8	113.28	2122.9		+30	Few Oscillations Poor
11	-	-	-	-	0	0	0	0	15.0	14.93	528.4	112.95	2123.0		7.5	3 Few Oscillations Poor

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
12	-	-	-	-	+5	+5	+5	+5	.0	15.08	527.7	113.46	2122.9		Pin-Pull 0	SWITCHED TO CANTED FINS 420 r.p.m. Steady-State
13	-	-	-	-	+5	+5	+5	+5	5.0	15.08	526.7	113.35	2122.9		0	420 r.p.m. Steady-State
14	-	-	-	-	+5	+5	+5	+5	10.0	14.87	526.0	112.47	2123.0		0	0 - Steady-State r.p.m.
15	-	-	-	-	+5	+5	+5	+5	15.0	15.10	526.0	113.35	2122.9		0	" "
16	-	-	-	-	+5	+5	+5	+5	20.0	15.12	526.0	113.42	2122.8		0	" "
17	-	-	-	-	+5	+5	+5	+5	25.0	15.10	525.8	113.32	2122.8		0	" "
18	-	-	-	-	+5	+5	+5	+5	30.0	15.08	525.8	113.25	2122.8		0	Steady-State Rate Mode Dual Mode
19	-	-	-	-	+5	+5	+5	+5	30.0	15.03	525.0	112.94	2122.9		52.5	Good Oscillations Lock-in Mode
20	-	-	-	-	+5	+5	+5	+5	25.0	15.26	516.4	112.99	2118.4		75.0	3 Oscillation to Steady-State Rate
																Switch to 0^{o} Tail Fins
21	-	-	-	-	0	0	0	0	30.0	15.04	519.8	112.57	2118.6		0	Lock-in Large Amplitude Damping
22	-	-	-	-	0	0	0		30.0	8.24	521.2	83.31	2125.7		45	Bad O Set

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}/δ_{C2}	δ_{C3}/δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}/δ_{T2}	δ_{T3}/δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
23	-/-	-/-	0/0	0/0	30.0	15.03	522.2	112.76	2118.6		45	Lock-in-Large Amplitude Build-up
										Tail Fins Off - Switch to Canards		
24	0/0	0/0	-/-	-/-	0^{o}	14.99	526.4	113.06	2118.7	Spun-Up Wand		Wand Pressure = 150 PSI Damping
25	0/0	0/0	-/-	-/-	5^{o}	15.26	526.4	114.08	2118.4	Spun-Up Wand		" "
										Shut Down - Main Generator		
26	0/0	0/0	-/-	-/-	10^{o}	15.20	526.7	114.07	2112.1	Spun-Up Wand		Wand Pressure = 150 PSI
27	0/0	0/0	-/-	-/-	15^{o}	14.99	527.0	113.30	2112.3	Spun-Up Wand		Lock-in at 15^{o}
28	0/0	0/0	-/-	-/-	20^{o}	14.83	527.7	112.79	2112.5	Spun-Up Wand		
29	0/0	0/0	-/-	-/-	25^{o}	15.08	527.7	113.74	2112.2	Spun-Up Wand		
30	0/0	0/0	-/-	-/-	30^{o}	15.28	528.1	114.51	2112.0	Spun-Up Wand		Possible Lock-in at 0^{o} and 45^{o}
31	0/0	0/0	-/-	-/-	30^{o}	15.28	532.7	115.01	2112.1		Pin-Pull 37.5	5 small oscillations at 0^{o} Lock-in
32	0/0	0/0	-/-	-/-	30^{o}	14.97	532.9	113.86	2112.4		$\frac{45}{225.0}$	Pin-Pull 45 + 180 = 225^{o} Small Oscillations at 45^{o}

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
33	0 / 0	0 / 0	- / -	- / -	25°	15.28	533.6	115.24	2107.1		37.5	Small Oscillations at 45°
34	0 / 0	0 / 0	- / -	- / -	25°	15.43	533.9	115.86	2107.0		22.5	Small Oscillations at 0° Vertical Lock-in
35	0 / 0	0 / 0	- / -	- / -	25°	15.12	534.3	114.73	2107.2		180+22.5 202.5	Small Oscillations at 0° Vertical Lock-in
36	0 / 0	0 / 0	- / -	- / -	20°	15.14	534.3	114.80	2107.2		30	Small Oscillations at 45° 5
37	0 / 0	0 / 0	- / -	- / -	20°	14.95	533.6	113.99	2107.4		0	5 Small Oscillations at 45°
38	0 / 0	0 / 0	- / -	- / -	15°	14.95	533.2	113.95	2107.5		0	5 Small Oscillations at 45°
										Changed Two	Canard	Angles - δ_{C1} and δ_{C3}
39	+10 / 0	+10 / 0	- / -	- / -	0°	15.28	531.2	114.98	2107.1		Pin-Pull 0	0 to Steady-State r.p.m. Steady-State 440 r.p.m.
40	+10 / 0	+10 / 0	- / -	- / -	5°	14.79	530.8	113.10	2107.6		Pin-Pull 0	0 to Steady-State r.p.m.
41	+10 / 0	+10 / 0	- / -	- / -	10°	15.31	530.7	115.08	2107.1		Pin-Pull 0	0 to Steady-State r.p.m.
42	+10 / 0	+10 / 0	- / -	- / -	15°	14.99	528.3	113.57	2107.4		Pin-Pull 0	0 to Steady-State r.p.m. Weak Lock-in or None
43	+10 / 0	+10 / 0	- / -	- / -	20°	15.03	528.1	113.69	2107.4		90	0 to Steady-State r.p.m.

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
44	+10	0	+10	0	-	-	-	-	20^{o}	15.12	527.7	114.02	2107.3		0	Small Amplitude Lock-in at -45^{o} } Lock-in every 180^{o}
45	+10	0	+10	0	-	-	-	-	20^{o}	14.97	527.0	113.36	2107.4		15	Large Amplitude Lock-in at -20^{o}
46	+10	0	+10	0	-	-	-	-	25^{o}	15.18	516.4	112.88	2112.1		Pin-Pull 90	0 to Steady-State r.p.m. No Oscillations
47	+10	0	+10	0	-	-	-	-	25^{0}	15.14	517.1	112.81	2112.0		Pin-Pull 45	Small Oscillations to Lock-in at 0^{o} and then +45^{o}
48	+10	0	+10	0	-	-	-	-	25^{o}	15.03	518.1	112.48	2112.3		Pin-Pull 15	Small Oscillations to Lock-in at 0^{o} (Lock-in Location every 180^{o})
49	+10	0	+10	0	-	-	-	-	30^{o}	15.01	518.8	112.49	2112.3		Pin-Pull 90	0 to Steady-State r.p.m.
50	+10	0	+10	0	-	-	-	-	30^{o}	15.03	521.9	112.90	2112.2		Pin-Pull 30	Q not exact Small Oscillations to Lock-in at 0^{o}
51	+10	0	+10	0	-	-	-	-	30^{o}	15.06	522.2	113.08	2112.3		Pin-Pull -60	Small Oscillations to Lock-in at -45^{o}
														Change Canards to		Pitch Up Control (+15)
52	+10	+15	+10	-15	-	-	-	-	0^{o}	15.01	521.9	112.82	2112.3		Pin-Pull 0	0 to Steady-State r.p.m.
53	+10	+15	+10	-15	-	-	-	-	5^{o}	15.06	522.2	113.08	2112.3		0	0 to Steady-State r.p.m.
54	+10	+15	+10	-15	-	-	-	-	10^{o}	14.87	522.5	112.37	2112.5		0	0 to Steady-State r.p.m. One Light Off

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (°R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
55	+10 / +15	+10 / -15	- / -	- / -	10°	14.95	522.6	112.68	2112.3		0	0 to Steady-State r.p.m.
56	+10 / +15	+10 / -15	- / -	- / -	15°	15.04	522.6	113.14	2108.8		0	0 to Steady-State r.p.m. Small Oscillation to Steady-State r.p.m.
57	+10 / +15	+10 / -15	- / -	- / -	20°	14.93	522.9	112.73	2108.9		0	Small Oscillation to Lock-in about - 45° Location (only position of lock-in)
58	+10 / +15	+10 / -15	- / -	- / -	20°	15.01	523.3	113.06	2108.8		$\frac{0 + 180}{180}$	0 to Steady-State r.p.m.
59	+10 / +15	+10 / -15	- / -	- / -	20°	15.03	523.6	113.18	2108.7		30	Large Oscillations to Lock-in at -45° (only position)
60	+10 / +15	+10 / -15	- / -	- / -	25°	15.08	524.0	113.43	2108.7		$\frac{0 + 180}{180}$	0 to Steady-State r.p.m.
61	+10 / +15	+10 / -15	- / -	- / -	25°	15.08	524.0	113.43	2108.7		30	Large Oscillations to Lock-in at -45° (only position)
62	+10 / +15	+10 / -15	- / -	- / -	30°	14.91	525.0	112.88	2108.9		$\frac{0 + 180}{180}$	0 to Steady-State r.p.m.
63	+10 / +15	+10 / -15	- / -	- / -	30°	15.04	525.7	113.47	2108.7		30	Large Oscillations to Lock-in at -45° position
64	+10 / +15	+10 / -15	- / -	- / -	30°	14.91	526.4	113.03	2108.9		$\frac{-52.5+180}{127.5}$	One or two oscillations to Lock-in at +225°
										Change	Canards to	Zero Roll Torque
65	0 / +15	0 / -15	- / -	- / -	0°	15.03	527.0	113.54	2108.8	Spun-Up Wand		No driving asymmetry

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}/δ_{C2}	δ_{C3}/δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}/δ_{T2}	δ_{T3}/δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
66	0 / +15	0 / -15	- / -	- / -	5^{o}	14.81	527.4	112.77	2109.0	Spun-Up Wand		No Lock-in
67	0 / +15	0 / -15	- / -	- / -	10^{o}	15.16	527.0	114.06	2108.6	Spun-Up Wand		
68	0 / +15	0 / -15	- / -	- / -	15^{o}	14.99	527.4	113.43	2108.8	Spun-Up Wand		Piece of Tape Loose
69	0 / +15	0 / -15	- / -	- / -	20^{o}	15.20	528.1	114.32	2108.6	Spun-Up Wand		
70	0 / +15	0 / -15	- / -	- / -	25^{o}	15.16	528.1	114.17	2108.6	Spun-Up Wand		Loose Tape
71	0 / +15	0 / -15	- / -	- / -	30^{o}	14.97	528.1	113.44	2108.8	Spun-Up Wand		
72	0 / +15	0 / -15	- / -	- / -	30^{o}	15.39	527.7	115.01	2108.4		Pin-Pull -60.0	Small or no Oscillations to Lock-in at -60^{o}
73	0 / +15	0 / -15	- / -	- / -	30^{o}	15.43	527.0	115.07	2108.4		Pin-Pull 30	2 Oscillations to Lock-in at -60^{o}
74	0 / +15	0 / -15	- / -	- / -	30^{o}	15.06	526.7	113.65	2108.7		Pin-Pull +120	Large Oscillations to Lock-in 3 Oscillations
75	0 / +15	0 / -15	- / -	- / -	25^{o}	15.30	526.4	114.49	2108.5		$\frac{-30+180}{150}$	Rotate to Lock-in Both Lock-ins covere
76	0 / +15	0 / -15	- / -	- / -	25^{o}	15.55	526.0	115.39	2108.2		30	3 Oscillations to Lock-in
77	0 / +15	0 / -15	- / -	- / -	20^{o}	15.06	513.3	112.10	2112.2		Pin-Pull 30	5 Large Oscillations to Lock-in at 270^{o}

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
78	0 / +15	0 / -15	- / -	- / -	20^o	15.08	514.0	112.25	2112.3		Pin-Pull 120	180^o - 60^o 2 Oscillations to Lock-in at 90^o
79	0 / +15	0 / -15	- / -	- / -	25^o	15.12	514.3	112.43	2112.2		120	180^o - 60^o 3 Oscillations to Lock-in at 90^o
80	0 / +15	0 / -15	- / -	- / -	15^o	15.12	515.4	112.55	2112.2		120	Only one Lock-in Position 3 Oscillations to Lock-in at 300^o
										Change Canards to		Off Axis Control Pitch
81	+15 / +15	-15 / -15	- / -	- / -	0^o	15.01	516.7	112.26	2112.3	Spun-Up		
82	+15 / +15	-15 / -15	- / -	- / -	5^o	14.76	517.0	111.34	2112.7	Spun-Up		
83	+15 / +15	-15 / -15	- / -	- / -	10^o	15.20	517.8	113.10	2112.1	Spun-Up		
84	+15 / +15	-15 / -15	- / -	- / -	15^o	14.99	517.4	112.26	2112.4	Spun-Up		Lock-in one Position
85	+15 / +15	-15 / -15	- / -	- / -	20^o	15.20	518.1	113.13	2112.1	Spun-Up		Lock-in one Position at 270^o
86	+15 / +15	-15 / -15	- / -	- / -	25^o	15.31	518.1	113.57	2112.0	Spun-Up		Lock-in at 90^o and 270^o both
87	+15 / +15	-15 / -15	- / -	- / -	30^o	15.08	518.1	112.70	2112.2	Spun-Up		Lock-in at 300^o, 160^o and 90^o (computer print wrong angle of α)
88	+15 / +15	-15 / -15	- / -	- / -	30^o	14.99	518.4	112.37	2112.4	Pin-Pull 120^o		2 Oscillations to Lock-in at 160^o

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
89	+15	+15	-15	-15	-	-	-	-	30^o	15.04	519.0	112.65	2112.3		Pin-Pull 180	2 Oscillations to Lock-in at 200^o
90	+15	+15	-15	-15	-	-	-	-	30^o	15.06	519.1	112.74	2112.3		Pin-Pull 30	4 Oscillations to Lock-in at 200^o
91	+15	+15	-15	-15	-	-	-	-	30^o	15.16	521.5	113.44	2109.3		Pin-Pull -45	2 Oscillations to Lock-in at 270^o
92	+15	+15	-15	-15	-	-	-	-	25^o	15.16	521.9	113.51	2108.1		Pin-Pull 120	4 Oscillations to Lock-in at 200^o (only lock-in)
93	+15	+15	-15	-15	-	-	-	-	20^o	14.93	522.2	112.68	2108.2		Pin-Pull 0	2 Oscillations to Lock-in at 200^o
94	+15	+15	-15	-15	-	-	-	-	15^o	14.74	522.1	111.93	2108.3		0	
														Add Tail	Fins and	Canards
95	0	0	0	0	0	0	0	0	0^o	14.85	523.3	112.51	2107.6	Spun-Up Wand		Wand Pressure = 200 PSI
96	0	0	0	0	0	0	0	0	5^o	15.03	523.3	113.18	2107.3	Spun-Up Wand		
97	0	0	0	0	0	0	0	0	10^o	14.89	523.6	112.70	2107.5	Spun-Up Wand		
98	0	0	0	0	0	0	0	0	15^o	14.89	523.6	112.70	2107.5	Spun-Up Wand		
99	0	0	0	0	0	0	0	0	20^o	15.26	523.3	114.05	2107.1	Spun-Up Wand		

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
100	0	0	0	0	0	0	0	0	25°	15.10	522.9	113.43	2107.4	Spun-Up Wand		
101	0	0	0	0	0	0	0	0	30°	15.10	523.3	113.46	2107.4	Spun-Up Wand		
102	0	0	0	0	0	0	0	0	30°	15.12	522.6	113.50	2106.0		Pin-Pull -45	Small Oscillations. About -45° Lock-in. Lock-in every 90°
103	0	0	0	0	0	0	0	0	30°	15.35	523.3	114.45	2105.6		Pin-Pull 0	Large Oscillations about -45° Lock-in
104	0	0	0	0	0	0	0	0	25°	15.03	523.3	113.21	2106.0		0	" "
105	0	0	0	0	0	0	0	0	20°	15.10	522.6	113.43	2105.8		0	" "
106	0	0	0	0	0	0	0	0	15°	15.18	522.9	113.76	2105.8		0	" "
107	0	0	0	0	0	0	0	0	10°	15.30	522.9	114.19	2105.6		0	One Oscillation to Lock-in at +45°
108	0	0	0	0	0	0	0	0	10°	15.06	522.9	113.32	2105.9		15	Two Oscillations to Lock-in at 45°
														Change Canard to		δ = +10 Roll Cant
109	+10	0	+10	0	0	0	0	0	0°	15.08	522.6	113.36	2105.9		0	0 to Steady-State r.p.m. = 120 r.p.m.
110	-10	0	+10	0	0	0	0	0	5°	15.03	522.2	113.12	2105.3		0	0 to Steady-State

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

	CONFIGURATION															
	CANARD DEFLECTION (DEG)				TAIL DEFLECTION (DEG)									INITIAL CONDITIONS		
RUN NO.	δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
111	+10	0	+10	0	0	0	0	0	10^{o}	15.01	522.2	113.04	2105.3		0	0 to Steady State Lock-in Weak (pin-pull didn't work)
112	+10	0	+10	0	0	0	0	0	15^{o}	15.12	521.5	113.41	2105.2	Spun-Up Wand		No Steady-State rate. 2 Lock-in positions (at 120^{o} and -60^{o})
113	+10	0	+10	0	0	0	0	0	20^{o}	14.99	521.5	112.90	2105.3	Spun-Up Wand		No Steady-State rate. 2 Lock-in positions (at 120^{o} and -60^{o})
114	+10	0	+10	0	0	0	0	0	25^{o}	14.91	521.5	112.60	2105.4	Spun-Up Wand		Steady-State rate (Slow) Lock-in at -45^{o} 4 positions (every 90^{o})
115	+10	0	+10	0	0	0	0	0	30^{o}	14.99	521.2	112.86	2105.3	Spun-Up Wand		Lock-in at -45^{o} 4 positions (every 90^{o}) Steady-State Rate
116	+10	0	+10	0	0	0	0	0	30^{o}	15.08	510.5	111.95	2109.4		180-22.5 157.5	Large Oscillations damped to lock-in at 135^{o} (4 positions of lock-in both case 180^{o} symmetric)
117	+10	0	+10	0	0	0	0	0	30^{o}	15.04	510.9	111.85	2109.4		195	Large Oscillations damped to Lock-in at 225^{o}
118	+10	0	+10	0	0	0	0	0	30^{o}	15.12	510.9	112.13	2109.3		0	0 to Steady-State r.p.m.
119	+10	0	+10	0	0	0	0	0	25^{o}	14.93	511.6	111.49	2109.5		157.5	Large damped oscillations to Lock-in at 135^{o}
120	+10	0	+10	0	0	0	0	0	25^{o}	15.22	511.9	112.61	2109.2		195	Only three Oscillations to Lock-in at 225^{o}. Steady-State r.p.m.
121	+10	0	+10	0	0	0	0	0	25^{o}	15.01	512.3	111.85	2109.5		0	Large damped oscillations to lock-in at $+45^{o}$. Steady-State r.p.m.
122	+10	0	+10	0	0	0	0	0	20^{o}	14.93	512.9	111.63	2109.6		30	Only 2 Lock-in positions at -30^{o} and 120^{o} No Steady-State r.p.m. Large damped oscillations

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (°R)	VEL. (FPS)	P (PSF)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
123	+10 / 0	+10 / 0	0 / 0	0 / 0	15°	14.78	514.7	111.24	2109.8		$\frac{180 + 30}{30}$	Wrong Pin-Pull at 218° (Lock-in present)
124	+10 / 0	+10 / 0	0 / 0	0 / 0	15°	15.04	514.7	112.26	2109.3		30	Lock-in at 210° weak. Large oscillations damped to lock-in at -60°
Bearing filters changed.										Change Canard		to Pitch deflections
125	+10 / +15	+10 / -15	0 / 0	0 / 0	0°	14.87	559.0	116.28	2111.0		0	0 to steady-state r.p.m.
126	+10 / +15	+10 / -15	0 / 0	0 / 0	5°	15.24	560.8	117.89	2110.6		0	0 to steady-state r.p.m. repeat run power on timing ~~light off.~~
127	10 / +15	+10 / -15	0 / 0	0 / 0	10°	15.06	561.8	117.32	2110.8		0	0 to steady-state r.p.m.
128	+10 / +15	+10 / -15	0 / 0	0 / 0	0°	14.99	524.1	113.02	2110.9		0	0 to steady-state r.p.m.
129	+10 / +15	+10 / -15	0 / 0	0 / 0	5°	15.33	524.0	114.32	2110.6		0	0 to steady-state r.p.m. Bearing Bad
130	+10 / +15	+10 / -15	0 / 0	0 / 0	5°	14.93	522.2	112.61	2110.9		0	0 to steady-state r.p.m.
131	+10 / +15	+10 / -15	0 / 0	0 / 0	10°	15.24	522.9	113.84	2110.6		0	0 to steady-state r.p.m.
132	+10 / +15	+10 / -15	0 / 0	0 / 0	15°	15.18	523.0	113.64	2110.6		0	Lock-in at 135° Large oscillations damped
133	+10 / +15	+10 / -15	0 / 0	0 / 0	15°	15.10	522.9	113.33	2110.8		-15	Large oscillations damping to lock-in at -45°

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	CANARD DEFLECTION (DEG) δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	TAIL DEFLECTION (DEG) δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (°R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	INITIAL CONDITIONS: PIN-PULL ANGLE (DEG)	REMARKS
134	+10 / +15	+10 / -15	0 / 0	C / 0	20°	15.10	522.6	113.30	2110.8		-15	Large oscillations damping to lock-in at -45°
135	+10 / +15	+10 / -15	0 / 0	0 / 0	20°	15.20	522.6	113.66	2110.7		0	Large oscillations damping to lock-in at -45°
136	+10 / +15	+10 / -15	0 / 0	0 / 0	20°	14.99	522.2	112.82	2110.9		+30	Large oscillations damping to lock-in at 135°
137	+10 / +15	+10 / -15	0 / 0	0 / 0	25°	14.93	521.9	112.57	2110.9		0	Large oscillations damping to lock-in at -45°
138	+10 / +15	+10 / -15	0 / 0	0 / 0	25°	15.20	521.2	113.51	2110.6		+15	Large oscillations damping to lock-in at +45°
139	+10 / +15	+10 / -15	0 / 0	0 / 0	25°	14.99	520.9	112.66	2111.6		120	Large oscillations damping to lock-in at 135°
140	+10 / +15	+10 / -15	0 / 0	0 / 0	25°	15.18	520.2	113.31	2111.4		210	Large oscillations to lock-in at 225°
141	+10 / +15	+10 / -15	0 / 0	0 / 0	30°	14.70	519.8	111.44	2111.9		0	Large oscillations to lock-in at -45°
BAD BEARING												
142	+10 / +15	+10 / -15	0 / 0	0 / 0	30°	14.99	507.9	111.00	2120.8		+15	Large oscillations to lock-in at +45°
143	+10 / +15	+10 / -15	0 / 0	0 / 0	30°	15.10	508.8	111.53	2120.7		180 - 60 / 120	Large oscillations to lock-in at +135° then Steady-State r.p.m.
144	+10 / +15	+10 / -15	0 / 0	0 / 0	30°	14.74	509.5	110.24	2121.1		210	Large oscillations to lock-in at -45°

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	CONFIGURATION: TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	INITIAL CONDITIONS: PIN-PULL ANGLE (DEG)	REMARKS
145	+10 / +15	+10 / -15	0 / 0	0 / 0	30^{o}	14.99	510.2	111.25	2120.8	Spun-Up		Damped to lock-in
146	+10 / +15	+10 / -15	0 / 0	0 / 0	25^{o}	14.93	511.2	111.15	2120.8	Spun-Up		Damped to steady-state r.p.m.
147	+10 / +15	+10 / -15	0 / 0	0 / 0	20^{o}	14.99	512.3	111.48	2120.8	Spun-Up		Damped to lock-in
148	+10 / +15	+10 / -15	0 / 0	0 / 0	15^{o}	15.06	513.3	111.88	2120.8	Spun-Up		Damped to lock-in
149	+10 / +15	+10 / -15	0 / 0	0 / 0	10^{o}	15.10	514.5	112.16	2120.7	Spun-Up		Damped to steady-state r.p.m.
150	+10 / +15	+10 / -15	0 / 0	0 / 0	5^{o}	15.18	515.4	112.54	2120.6	Spun-Up		Damped to steady-state r.p.m.
151	+10 / +15	+10 / -15	0 / 0	0 / 0	0^{o}	15.37	516.4	113.37	2120.4	Spun-Up		Damped to steady-state r.p.m.
										CHANGE CANARD TO PITCH DEFLECTION ONLY		
152	0 / +15	0 / -15	0 / 0	0 / 0	0^{o}	15.01	517.4	112.11	2120.8	Spun-Up		No roll at 0^{o}
153	0 / +15	0 / -15	0 / 0	0 / 0	5^{o}	15.20	518.8	112.98	2120.6	Spun-Up		Damped to a lock-in with pitch fins vertical at 270^{o}
154	0 / +15	0 / -15	0 / 0	0 / 0	10^{o}	15.03	523.3	112.83	2120.1	Spun-Up		Lock-in present Damped to lock-in
155	0 / +15	0 / -15	0 / 0	0 / 0	15^{o}	15.16	524.3	113.45	2120.0	Spun-Up		Lock-in at -45^{o}, 135^{o}, 225^{o} Damped to lock-in

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}		TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (°R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
	δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}										
156	0 / +15	0 / -15	0 / 0	0 / 0	20°	15.06	525.0	113.16	2120.1	Spun-Up		Lock-in at -45, +45, 135, 225° Damped to lock-in
157	0 / +15	0 / -15	0 / 0	0 / 0	25°	15.10	525.0	113.31	2120.0	Spun-Up		Lock-in at -45, +45, 135, 225° Damped to lock-in
158	0 / +15	0 / -15	0 / 0	0 / 0	30°	15.10	525.0	113.31	2120.0	Spun-Up		Lock-in at -45, +45, 135, 225° Damped to lock-in
159	0 / +15	0 / -15	0 / 0	0 / 0	30°	14.93	525.2	112.68	2120.2		Pin-Pull 0	Large oscillations to lock-in at 225° Did not damp
160	0 / +15	0 / -15	0 / 0	0 / 0	30°	15.22	525.0	113.75	2119.9		Pin-Pull 30	Undamped oscillations about lock-in at +45°
161	0 / +15	0 / -15	0 / 0	0 / 0	30°	15.20	525.3	113.71	2119.9		Pin-Pull 120	Undamped oscillations about lock-in at 135°
162	0 / +15	0 / -15	0 / 0	0 / 0	30°	15.28	525.4	114.01	2119.9		Pin-Pull -30	Undamped oscillations about lock-in at -45°
163	0 / +15	0 / -15	0 / 0	0 / 0	25°	15.18	525.7	113.68	2119.9		Pin-Pull 0	Damped oscillations to lock-in at -45°
164	0 / +15	0 / -15	0 / 0	0 / 0	25°	15.08	525.7	113.31	2120.0		Pin-Pull 30	Damped to lock-in at +45°
165	0 / +15	0 / -15	0 / 0	0 / 0	25°	15.14	526.0	113.57	2120.1		120	Damped to lock-in at 135°
166	0 / +15	0 / -15	0 / 0	0 / 0	25°	15.31	526.4	114.26	2119.8		210	Damped to lock-in at 225°
167	0 / +15	0 / -15	0 / 0	0 / 0	20°	15.35	526.4	114.40	2119.7		0	Damped to lock-in at -45°

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C3} / δ_{C4}	CONFIGURATION: TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	CONFIGURATION: TAIL DEFLECTION (DEG) δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	INITIAL CONDITIONS: PIN-PULL ANGLE (DEG)	REMARKS
168	0 / +15	0 / -15	0 / 0	0 / 0	20^{o}	15.14	526.7	113.68	2118.5		30	Damped to lock-in at 135^{o}
169	0 / +15	0 / -15	0 / 0	0 / 0	20^{o}	15.04	526.7	113.32	2118.7		210	Damped to lock-in at 225^{o}
170	0 / +15	0 / -15	0 / 0	0 / 0	15^{o}	15.14	526.7	113.68	2118.5		0	Damp oscillations to lock-in at 135^{o}
171	0 / +15	0 / -15	0 / 0	0 / 0	15^{o}	15.20	526.7	113.90	2118.4		-30	Damped small oscillations (2) to lock-in at -45^{o}
172	0 / +15	0 / -15	0 / 0	0 / 0	15^{o}	14.91	527.0	112.84	2118.8		210	Damped small oscillations (2) to lock-in at 225^{o}
173	0 / +15	0 / -15	0 / 0	0 / 0	10^{o}	14.99	526.7	113.10	2118.6		0	Damped large oscillations to lock-in at 90^{o}
											CHANGE CANARD	
174	+15 / +15	-15 / -15	0 / 0	0 / 0	0^{o}	14.93	525.4	112.74	2118.7	Spun-Up		Small roll rates positive and negative
175	+15 / +15	-15 / -15	0 / 0	0 / 0	5^{o}	15.12	525.7	113.50	2118.6	Spun-Up		Damped to lock-in at 90^{o}
176	+15 / +15	-15 / -15	0 / 0	0 / 0	10^{o}	14.87	525.3	112.51	2118.7	Spun-Up		Damped to lock-in at (+45^{o} only)
177	+15 / +15	-15 / -15	0 / 0	0 / 0	15^{o}	15.12	525.0	113.43	2118.4	Spun-Up		Damped to lock-in at (+45^{o} only)
178	+15 / +15	-15 / -15	0 / 0	0 / 0	20^{o}	15.39	525.0	114.44	2118.2	Spun-Up		Damped to lock-in at -30, +45, +135, +225

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
179	+15 / +15	-15 / -15	0 / 0	0 / 0	25°	15.10	523.6	113.20	2118.6	Spun-Up		Damped to lock-in +45°, 135° Lock-in at -45°, 225°
180	+15 / +15	-15 / -15	0 / 0	0 / 0	30°	15.03	524.0	112.95	2118.6	Spun-Up		Damped to lock-in +45°, 135° Lock-in at -45°, 225°
181	+15 / +15	-15 / -15	0 / 0	0 / 0	30°	15.12	523.6	113.27	2118.5		Pin-Pull 0	Damped to lock-in at 135°
182	+15 / +15	-15 / -15	0 / 0	0 / 0	30°	14.97	523.3	112.65	2118.7		-30	Damped to lock-in at 225°
183	+15 / +15	-15 / -15	0 / 0	0 / 0	30°	15.14	523.3	113.31	2118.4		30	Damped to lock-in at +45°
184	+15 / +15	-15 / -15	0 / 0	0 / 0	30°	15.22	522.9	113.56	2118.4		-60	Damped to lock-in at -45°
185	+15 / +15	-15 / -15	0 / 0	0 / 0	25°	14.97	522.7	112.59	2118.7		-45	Damped to lock-in at -45°
186	+15 / +15	-15 / -15	0 / 0	0 / 0	25°	14.79	522.6	111.92	2118.8		0	Damped in 3 oscillations to lock-in at 225°
187	+15 / +15	-15 / -15	0 / 0	0 / 0	25°	14.93	521.9	112.38	2117.9		30	Damped to lock-in at +45°
188	+15 / +15	-15 / -15	0 / 0	0 / 0	25°	14.81	521.5	111.90	2118.2		120	Damp to lock-in at 135°
189	+15 / +15	-15 / -15	0 / 0	0 / 0	20°	14.87	521.5	112.12	2118.0		0	Damped to lock-in at -45°
190	+15 / +15	-15 / -15	0 / 0	0 / 0	20°	15.16	521.2	113.18	2117.7		30	Damped to lock-in at +45°

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	INITIAL CONDITIONS: PIN-PULL ANGLE (DEG)	REMARKS
191	+15 / +15	-15 / -15	0 / 0	0 / 0	20^{o}	15.30	514.7	112.93	2119.0		120	Small damped and undamped to lock-in to 135^{o}
192	+15 / +15	-15 / -15	0 / 0	0 / 0	20^{o}	15.08	515.4	112.21	2119.3		210	Small damped oscillations to lock-in at 225^{o}
193	+15 / +15	-15 / -15	0 / 0	0 / 0	15^{o}	14.81	515.7	111.24	2119.6		0	Damps with small oscillation to lock-in at $+45^{o}$
194	+15 / +15	-15 / -15	0 / 0	0 / 0	15^{o}	14.93	516.4	111.75	2119.3		180	Damps with small oscillation to lock-in at $+45^{o}$
195	+15 / +15	-15 / -15	0 / 0	0 / 0	10^{o}	15.04	516.7	112.22	2119.3		180	Damps with many large oscillations to lock-in at $+45^{o}$
196	+15 / +15	-15 / -15	0 / 0	0 / 0	10^{o}	15.24	517.4	113.02	2119.1		180	Lights off on 195. Repeat of 195
197	+15 / +15	-15 / -15	0 / 0	0 / 0	5^{o}	15.18	518.1	112.87	2119.2		0	Damps with many large oscillations to lock-in at $+45^{o}$
198	+15 / +15	-15 / -15	0 / 0	0 / 0	5^{o}	15.22	518.8	113.10	2119.1		180	Damps with many large oscillations to lock-in at $+45^{o}$
										CHANGE TO 5 CANTED TAIL FINS		
199	+15 / +15	-15 / -15	5 / 5	5 / 5	0^{o}	15.14	519.1	112.84	2119.2		0	0 to steady-state r.p.m.
200	+15 / +15	-15 / -15	5 / 5	5 / 5	5^{o}	14.91	520.2	112.08	2119.5		0	0 to steady-state r.p.m.
201	+15 / +15	-15 / -15	5 / 5	5 / 5	10^{o}	15.18	520.9	113.17	2119.2		0	0 to steady-state r.p.m.

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	CANARD DEFLECTION (DEG) δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	TAIL DEFLECTION (DEG) δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	INITIAL CONDITIONS: PIN-PULL ANGLE (DEG)	REMARKS
202	+15 / +15	-15 / -15	5 / 5	5 / 5	15^o	15.01	520.5	112.48	2119.4		0	0 to steady-state r.p.m.
203	+15 / +15	-15 / -15	5 / 5	5 / 5	20^o	15.04	520.9	112.63	2120.8		0	0 to steady-state r.p.m.
204	+15 / +15	-15 / -15	5 / 5	5 / 5	25^o	15.20	520.9	113.21	2120.6		0	0 to steady-state r.p.m.
205	+15 / +15	-15 / -15	5 / 5	5 / 5	30^o	15.06	520.5	112.66	2120.8		0	0 to steady-state r.p.m. Lock-in -45, +45, 225^o
206	+15 / +15	-15 / -15	5 / 5	5 / 5	forgot α label 30^o	15.12	520.5	112.88	2120.7		-30	Damped oscillations to lock-in at -45^o
207	+15 / +15	-15 / -15	5 / 5	5 / 5	forgot α label 30^o	15.28	520.9	113.50	2120.6		+30	0 to steady-state r.p.m. there is lock-in about $+45^o$
208	+15 / +15	-15 / -15	5 / 5	5 / 5	30^o	15.35	521.1	113.81	2120.4		210	Large undamped oscillations about lock-in at 225^o
209	+15 / +15	-15 / -15	5 / 5	5 / 5	25^o	15.22	522.2	113.43	2120.6		-30	Large undamped oscillations about -45^o lock-in
210	+15 / +15	-15 / -15	5 / 5	5 / 5	25^o	15.08	523.3	113.03	2120.8		+30	0 to steady-state r.p.m.
211	+15 / +15	-15 / -15	5 / 5	5 / 5	30^o	15.10	523.6	113.14	2120.7		120	0 to steady-state r.p.m.
212	+15 / +15	-15 / -15	5 / 5	5 / 5	25^o	15.14	524.0	113.34	2120.0		210	0 to steady-state r.p.m. Lock-in noted using wand at 225^o
213	+15 / +15	-15 / -15	5 / 5	5 / 5	20^o	15.10	524.6	113.27	2120.0		-30	0 to steady-state r.p.m.

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
										CHANGE	CANARD	PITCH ON AXIS CONTROL DEFLECTION
214	0 / +15	0 / -15	5 / 5	5 / 5	0^{o}	15.18	525.6	113.72	2117.8		0	0 to steady-state r.p.m.
215	0 / +15	0 / -15	5 / 5	5 / 5	5^{o}	15.18	526.7	113.84	2117.9		0	0 to steady-state r.p.m.
216	0 / +15	0 / -15	5 / 5	5 / 5	10^{o}	15.08	527.4	113.59	2116.5		0	0 to steady-state r.p.m.
217	0 / +15	0 / -15	5 / 5	5 / 5	15^{o}	14.70	527.0	112.09	2116.9		0	0 to steady-state r.p.m.
218	0 / +15	0 / -15	5 / 5	5 / 5	20^{o}	15.16	527.4	113.88	2116.4		0	0 to steady-state r.p.m.
219	0 / +15	0 / -15	5 / 5	5 / 5	25^{o}	15.12	527.7	113.78	2116.5		0	0 to steady-state r.p.m.
220	0 / +15	0 / -15	5 / 5	5 / 5	30^{o}	15.14	527.0	113.77	2116.5		0	0 to steady-state r.p.m.
221	0 / +15	0 / -15	5 / 5	5 / 5	30^{o}	14.95	527.4	113.08	2116.7		-30	Damped to lock-in at -45^{o}
222	0 / +15	0 / -15	5 / 5	5 / 5	30^{o}	15.16	527.4	113.88	2116.4		+30	0 to steady-state r.p.m. (Lock-in noted with wand at $+45^{o}$)
223	0 / +15	0 / -15	5 / 5	5 / 5	30^{o}	15.12	527.2	113.71	2116.5		120	0 to steady-state r.p.m.
224	0 / +15	0 / -15	5 / 5	5 / 5	30^{o}	15.06	527.0	113.48	2116.5		135	Undamped from 135^{o} lock-in to steady-state r.p.m. (small oscillations to large)

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	CONFIGURATION: TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
225	0 / +15	0 / -15	5 / 5	5 / 5	30^o	15.31	527.0	114.43	2116.3		210	0 to steady-state r.p.m. (Lock-in noted at 225^o with wand)
226	0 / +15	0 / -15	5 / 5	5 / 5	25^o	15.12	526.4	113.63	2116.5		-30	Damped to lock-in at -45^o
227	0 / +15	0 / -15	5 / 5	5 / 5	25^o	15.08	526.7	113.52	2116.6		135	0 to steady-state r.p.m.
228	0 / +15	0 / -15	5 / 5	5 / 5	25^o	15.10	527.0	113.63	2116.4		210	(Lock-in at -45, +80, 225^o) 0 to steady-state r.p.m.
											CHANGED	CANARD
229	+10 / +15	+10 / -15	5 / 5	5 / 5	0^o	15.06	526.0	113.39	2115.8		0	0 to steady-state 100 fps
230	+10 / +15	+10 / -15	5 / 5	5 / 5	5^o	15.04	526.0	113.32	2115.9		0	0 to steady-state 100 fps
731	+10 / +15	+10 / -15	5 / 5	5 / 5	0^o	15.06	525.3	113.32	2115.7		0	Changed camera speed to 200 fps 0 to steady-state r.p.m.
232	+10 / +15	+10 / -15	5 / 5	5 / 5	5^o	15.14	524.6	113.53	2115.7		0	0 to steady-state r.p.m.
233	+10 / +15	+10 / -15	5 / 5	5 / 5	10^o	15.20	525.3	113.83	2115.6		0	0 to steady-state r.p.m.
234	+10 / +15	+10 / -15	5 / 5	5 / 5	15^o	14.93	525.3	112.81	2115.9		0	0 to steady-state r.p.m.
235	+10 / +15	+10 / -15	5 / 5	5 / 5	20^o	15.14	525.3	113.61	2115.7		0	0 to steady-state r.p.m.

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	I (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
236	+10 / +15	+10 / -15	5 / 5	5 / 5	25°	15.14	524.0	113.46	2115.6		0	0 to steady-state r.p.m.
237	+10 / +15	+10 / -15	5 / 5	5 / 5	30°	15.08	524.0	113.24	2115.8		0	Lock-in at -45, 135, 225° using wand. 0 to steady-state r.p.m.
238	+10 / +15	+10 / -15	5 / 5	5 / 5	30°	15.08	523.6	113.20	2115.8		-30	Small oscillations to lock-in at -45°
239	+10 / +15	+10 / -15	5 / 5	5 / 5	30°	15.16	523.6	113.49	2115.7		135	Small oscillations to lock-in at 135°
240	+10 / +15	+10 / -15	5 / 5	5 / 5	30°	14.91	523.6	112.55	2116.0		210	0 to steady-state r.p.m.
241	+10 / +15	+10 / -15	5 / 5	5 / 5	25°	15.08	522.5	113.08	2115.7		-30	Lock-in at -45° using wand. Damped small lock-in at -45° No lock-in at 20°
										CHANGE CANARD NO PITCH		
242	+10 / 0	+10 / 0	5 / 5	5 / 5	0°	15.39	521.5	114.14	2115.5		0	0 to steady-state r.p.m.
243	+10 / 0	+10 / 0	5 / 5	5 / 5	5°	15.10	521.9	113.09	2115.8		0	0 to steady-state r.p.m.
244	+10 / 0	+10 / 0	5 / 5	5 / 5	10°	15.16	521.5	113.27	2115.7		0	0 to steady-state r.p.m.
245	+10 / 0	+10 / 0	5 / 5	5 / 5	15°	15.03	510.9	111.60	2115.8		0	0 to steady-state rate
246	+10 / 0	+10 / 0	5 / 5	5 / 5	20°	14.89	511.6	111.17	2116.0		0	0 to steady-state rate

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}/δ_{C2}	δ_{C3}/δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}/δ_{T2}	δ_{T3}/δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
247	+10/0	+10/0	5/5	5/5	25°	15.24	512.3	112.55	2115.6		0	0 to steady-state rate
248	+10/0	+10/0	5/5	5/5	30°	15.28	512.6	112.73	2115.6		0	
249	+10/0	+10/0	5/5	5/5	30°	15.31	513.3	112.95	2115.5		-30	Lock-in at 4 positions. Wand Small oscillations damped -45°
250	+10/0	+10/0	5/5	5/5	30°	15.26	514.0	112.81	2115.6		210	Symmetric configuration 0 to steady-state rate
251	+10/0	+10/0	5/5	5/5	25°	15.01	515.4	112.02	2115.8		-30	Lock-in -45 and 135 ward Small oscillations or none.
252	+10/0	+10/0	5/5	5/5	25°	15.04	515.4	112.16	2115.8		-15	0 to steady-state rate
											CHANGE	CANARD
253	0/0	0/0	5/5	5/5	0°	15.08	515.0	112.27	2115.7		0	0 to steady-state rate
254	0/0	0/0	5/5	5/5	5°	15.14	516.2	112.61	2115.7		0	0 to steady-state rate
255	0/0	0/0	5/5	5/5	10°	15.03	516.4	112.20	2115.9		0	0 to steady-state rate
256	0/0	0/0	5/5	5/5	15°	14.97	516.7	112.02	2115.9		0	0 to steady-state rate
257	0/0	0/0	5/5	5/5	20°	15.26	516.7	113.11	2115.6		0	0 to steady-state rate

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}/δ_{C2}	δ_{C3}/δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}/δ_{T2}	δ_{T3}/δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
258	0/0	0/0	5/5	5/5	25°	15.06	517.4	112.46	2115.8		0	0 to steady-state rate
259	0/0	0/0	5/5	5/5	30°	14.95	517.4	112.02	2115.9		-22.5	0 to steady-state rate
260	0/0	0/0	5/5	5/5	30°	15.08	518.1	112.61	2115.8		-22.5	8 oscillations to lock-in at -45°
CHANGE TO TAIL WITH 0° CANT												
261	-/-	-/-	0/0	0/0	30°	15.12	519.0	112.85	2115.8	Spun-Up		
REPLACED REAR CARBON BEARING												
262	0/0	0/0	0/0	0/0	0°	15.04	526.2	113.38	2114.4	Spun-Up		
263	0/0	0/0	0/0	0/0	5°	15.12	525.7	113.61	2114.4	Spun-Up		
264	0/0	0/0	0/0	0/0	10°	14.93	525.0	112.80	2114.6	Spun-Up		Weak lock-in noted at -45°
265	0/0	0/0	0/0	0/0	15°	14.89	525.0	112.66	2114.6	Spun-Up		Lock-in noted
266	0/0	0/0	0/0	0/0	20°	15.06	525.0	113.32	2114.4	Spun-Up		Lock-in noted
267	0/0	0/0	0/0	0/0	25°	15.10	525.0	113.46	2114.3	Spun-Up		Lock-in noted

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}		TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}		YAW ANGLE (DEG)	Q (PSF)	TEMP. (°R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
	δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}								
268	0 / 0	0 / 0	0 / 0	0 / 0	30°	15.12	524.6	113.50	2114.4	Spun-Up		Lock-in noted
											CHANGED TAIL CANT	
269	0 / 0	0 / 0	5 / 5	5 / 5	0°	15.06	524.0	113.21	2114.4		Pin-Pull 0	0 to steady-state rate
270	0 / 0	0 / 0	5 / 5	5 / 5	5°	15.22	524.0	113.79	2114.2		0	0 to steady-state rate
271	0 / 0	0 / 0	5 / 5	5 / 5	10°	14.97	522.9	112.73	2114.5		0	0 to steady-state rate
272	0 / 0	0 / 0	5 / 5	5 / 5	15°	14.93	523.3	112.62	2114.5		0	0 to steady-state rate
273	0 / 0	0 / 0	5 / 5	5 / 5	20°	14.91	523.3	112.55	2114.6		0	0 to steady-state rate
274	0 / 0	0 / 0	5 / 5	5 / 5	25°	15.14	522.9	113.38	2114.3		0	0 to steady-state rate
275	0 / 0	0 / 0	5 / 5	5 / 5	30°	15.39	522.9	114.32	2114.1		0	0 to steady-state rate
											CHANGED CANARD ANGLES	
276	0 / +15	0 / -15	5 / 5	5 / 5	0°	15.01	521.5	112.75	2113.7		0	
277	0 / +15	0 / -15	5 / 5	5 / 5	5°	15.18	521.9	113.44	2113.6		0	

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION CANARD DEFLECTION (DEG) δ_{C1}/δ_{C2}	δ_{C3}/δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}/δ_{T2}	δ_{T3}/δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
278	0/+15	0/-15	5/5	5/5	10^{o}	15.14	508.5	111.40	2129.9		0	0 to steady-state rate
279	0/+15	0/-15	5/5	5/5	15^{o}	14.91	509.5	110.65	130.1		0	0 to steady-state rate
280	0/+15	0/-15	5/5	5/5	20^{o}	15.10	509.8	111.41	2129.9		0	0 to steady-state rate
281	0/+15	0/-15	5/5	5/5	25^{o}	15.28	510.5	112.13	2129.7		0	0 to steady-state rate
282	0/+15	0/-15	[illegible]	5/5	30^{o}	15.03	511.2	111.27	2130.0		0	
											CHANGE TAIL FINS 0^{o} CANT	
283	0/+15	0/-15	0/0	0/0	0^{o}	14.95	512.3	111.10	2130.0	Spun-Up		Two titles
284	0/+15	0/-15	0/0	0/0	5^{o}	15.01	512.9	111.38	2130.0	Spun-Up		Damps
285	0/+15	0/-15	0/0	0/0	10^{o}	15.20	513.3	112.14	2129.8	Spun-Up		Damps
286	0/+15	0/-15	0/0	0/0	15^{o}	15.08	513.6	111.75	2129.9	Spun-Up		Damps to lock-in
287	0/+15	0/-15	0/0	0/0	20^{o}	15.12	514.0	111.93	2129.9	Spun-Up		Damps to lock-in
288	0/+15	0/-15	0/0	0/0	25^{o}	15.04	514.3	111.68	2129.9	Spun-Up		Damps to lock-in

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}/δ_{C2}	δ_{C3}/δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}/δ_{T2}	δ_{T3}/δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
289	0/+15	0/-15	0/0	0/0	30°	15.01	517.1	111.83	2130.0	Spun-Up		Damps to lock-in
											CHANGE	CANARD
290	+10/+15	+10/-15	0/0	0/0	0°	15.22	518.8	112.81	2129.8		Pin-Pull 0	0 to steady-state rate
291	+10/+15	+10/-15	0/0	0/0	5°	14.91	519.8	111.76	2130.1		0	0 to steady-state rate
292	+10/+15	+10/-15	0/0	0/0	10°	15.08	520.9	112.53	2129.9		0	0 to steady-state rate
293	+10/+15	+10/-15	0/0	0/0	15°	15.22	521.2	113.07	2129.8		0	Forgot to set printout Damped to lock-in at +90°
294	+10/+15	+10/-15	0/0	0/0	15°	14.97	522.2	112.24	2130.1	Spun-Up		Damped to lock-in at +45°
295	+10/+15	+10/-15	0/0	0/0	20°	14.93	522.9	112.17	2130.1	Spun-Up		Damped to lock-in at 135°
296	+10/+15	+10/-15	0/0	0/0	25°	15.20	523.3	113.22	2129.8	Spun-Up		Damped to steady-state r.p.m.
297	+10/+15	+10/-15	0/0	0/0	30°	14.99	523.6	112.46	2130.0	Spun-Up		Damped to steady-state r.p.m.
298	+10/+15	+10/-15	0/0	0/0	30°	0.00	521.0	0.00	2145.1		Pin-Pull 0	Damped to lock-in at -45° Forgot to punch printer
299	+10/+15	+10/-15	0/0	0/0	30°	14.[illegible]	524.0	112.50	2130.1		Pin-Pull 0	Damped to lock-in at +45°

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
300	+10 / +15	+10 / -15	0 / 0	0 / 0	25°	15.04	525.0	112.83	2129.9		0	Damped to lock-in at +45°
											CHANGE	TO 5° CANT TAIL
301	+10 / +15	+10 / -15	5 / 5	5 / 5	0°	15.04	526.0	112.94	2130.0		0	0 to steady-state rate
302	+10 / +15	+10 / -15	5 / 5	5 / 5	5°	15.26	526.4	113.78	2129.8		0	0 to steady-state rate 200 fps 10 cycles per second omitted
303	+10 / +15	+10 / -15	5 / 5	5 / 5	10°	15.16	526.7	113.45	2129.8		0	0 to steady-state rate
304	+10 / +15	+10 / -15	5 / 5	5 / 5	15°	15.04	527.0	113.05	2130.0		0	0 to steady-state rate
305	+10 / +15	+10 / -15	5 / 5	5 / 5	20°	14.91	527.7	112.61	2130.1		0	0 to steady-state rate
306	+10 / +15	+10 / -15	5 / 5	5 / 5	25°	14.95	527.7	112.76	2130.1		0	0 to steady-state rate
307	+10 / +15	+10 / -15	5 / 5	5 / 5	30°	15.04	530.5	113.42	2130.0		0	0 to steady-state rate
											CHANGE	CANARDS TO OFF AXIS PITCH
308	+15 / +15	-15 / -15	5 / 5	5 / 5	0°	14.87	532.6	113.13	2124.5		0	0 to steady-state
309	+15 / +15	-15 / -15	5 / 5	5 / 5	5°	15.26	532.9	114.63	2124.1		0	0 to steady-state

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	q (PSF)	TEMP. (°R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
310	+15	+15	-15	-15	5	5	5	5	10°	15.01	533.5	113.74	2124.3		0	0 to steady-state
311	+15	+15	-15	-15	5	5	5	5	15°	14.95	533.6	113.53	2124.4		0	0 to steady-state
312	+15	+15	-15	-15	5	5	5	5	20°	15.08	532.9	113.97	2124.3		0	0 to steady-state
313	+15	+15	-15	-15	5	5	5	5	25°	14.93	533.7	113.47	2124.5		0	
314	+15	+15	-15	-15	5	5	5	5	30°	15.01	534.3	113.83	2124.4		0	
															CHANGE	TO 0° CANT TAIL
315	+15	+15	-15	-15	0	0	0	0	0°	14.85	534.0	113.21	2124.5	Spun-Up		
316	+15	+15	-15	-15	0	0	0	0	5°	15.12	534.6	114.30	2124.2	Spun-Up		Damps to lock-in at +45°
317	+15	+15	-15	-15	0	0	0	0	10°	15.06	534.6	114.09	2124.3	Spun-Up		Damps to lock-in at +45°
318	+15	+15	-15	-15	0	0	0	0	15°	14.97	534.3	113.68	2124.4	Spun-Up		
319	+15	+15	-15	-15	0	0	0	0	20°	15.10	534.6	114.23	2124.3	Spun-Up		Damps to lock-in at +45°
320	+15	+15	-15	-15	0	0	0	0	25°	15.10	535.0	114.27	2124.2	Spun-Up		Damps to lock-in at +135°

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
321	+15	+15	-15	-15	0	0	0	0	30^{o}	19.12	535.0	114.34	2124.2	Spun-Up		Damps to lock-in at 225^{o}
															CHANGE	CANARD REMOVE CONTROL DEFLECTION
322	+10	0	+10	0	0	0	0	0	0^{o}	15.28	534.3	114.91	2121.9		Pin-Pull 0	0 to steady-state rate
323	+10	0	+10	0	0	0	0	0	5^{o}	15.24	535.0	114.84	2122.0		0	0 to steady-state rate
324	+10	0	+10	0	0	0	0	0	10^{o}	14.93	535.0	113.66	2122.3		0	0 to steady-state rate
325	+10	0	+10	0	0	0	0	0	15^{o}	15.01	533.6	113.81	2122.2		0	Damping to lock-in at -45^{o}
326	+10	0	+10	0	0	0	0	0	20^{o}	15.16	534.3	114.47	2122.1		0	Damping to lock-in at -45^{o}
327	+10	0	+10	0	0	0	0	0	25^{o}	15.08	534.6	114.21	2122.2		0	Damping to lock-in at +45^{o}
328	+10	0	+10	0	0	0	0	0	30^{o}	15.24	534.6	114.80	2122.0		0	0 to steady-state rate
329	+10	0	+10	0	0	0	0	0	30^{o}	15.12	534.6	114.36	2122.1	Spun-Up		Damps to steady-state rate
330	+10	0	+10	0	0	0	0	0	25^{o}	15.30	534.3	114.98	2121.9	Spun-Up		Damps to steady-state rate
331	+10	0	+10	0	0	0	0	0	20^{o}	15.31	534.5	115.12	2120.5	Spun-Up		Damps to lock-in at +135^{o}

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

	CONFIGURATION									INITIAL CONDITIONS		
	CANARD DEFLECTION (DEG)		TAIL DEFLECTION (DEG)									
RUN NO.	δ_{C1} / δ_{C2}	δ_{C3} / δ_{C4}	δ_{T1} / δ_{T2}	δ_{T3} / δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
332	+10 / 0	+10 / 0	0 / 0	0 / 0	15^{o}	15.31	534.4	115.11	2120.5	Spun-Up		Damps to steady-state rate
											CHANGED	TO 5^{o} TAIL CANT
333	+10 / 0	+10 / 0	5 / 5	5 / 5	0^{o}	15.14	534.3	114.44	2120.6		Pin-Pull 0	0 to steady-state rate
334	+10 / 0	+10 / 0	5 / 5	5 / 5	5^{o}	15.16	534.3	114.51	2120.6		0	0 to steady-state rate
335	+10 / 0	+10 / 0	5 / 5	5 / 5	10^{o}	14.87	533.5	113.32	2121.0		0	0 to steady-state rate
336	+10 / 0	+10 / 0	5 / 5	5 / 5	15^{o}	15.20	533.6	114.58	2120.6		0	0 to steady-state rate
337	+10 / 0	+10 / 0	5 / 5	5 / 5	20^{o}	15.1C	533.2	114.18	2120.7		0	0 to steady-state rate
338	+10 / 0	+10 / 0	5 / 5	5 / 5	25^{o}	15.06	532.8	113.99	2120.7		0	0 to steady-state rate
339	+10 / 0	+10 / 0	5 / 5	5 / 5	30^{o}	14.97	532.8	113.62	2120.9		0	0 to steady-state rate
											REMOVED	CANARD FINS
340	- / -	- / -	5 / 5	5 / 5	0^{o}	15.04	517.1	112.39	2114.4		0	0 to steady-state rate
341	- / -	- / -	5 / 5	5 / 5	5^{o}	14.91	517.4	111.92	2114.6		0	

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^{o}R)	VEL. (FPS)	P (PSFA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
342	-	-	-	-	5	5	5	5	10^{o}	15.10	518.4	112.75	2114.4		0	
343	-	-	-	-	5	5	5	5	15^{o}	15.04	518.8	112.57	2114.4		0	
344	-	-	-	-	5	5	5	5	20^{o}	15.03	519.5	112.58	2114.4		0	
345	-	-	-	-	5	5	5	5	25^{o}	15.08	519.8	112.83	2114.3		0	
346	-	-	-	-	5	5	5	5	30^{o}	15.04	520.2	112.72	2114.4		0	
															CHANGE	TAIL CANT TO 0^{o}
347	-	-	-	-	0	0	0	0	0^{o}	14.93	520.5	112.32	2114.5	Spun-Up		
348	-	-	-	-	0	0	0	0	5^{o}	15.06	520.9	112.87	.4	Spun-Up		
349	-	-	-	-	0	0	0	0	10^{o}	15.06	521.2	112.91	2114.4	Spun-Up		No lock-in at 10^{o}
350	-	-	-	-	0	0	0	0	15^{o}	15.14	521.5	113.24	2114.3	Spun-Up		Weak lock-in at $+45^{o}$
351	-	-	-	-	0	0	0	0	20^{o}	15.10	522.2	113.16	2114.4	Spun-Up		
352	-	-	-	-	0	0	0	0	25^{o}	14.99	522.9	112.80	2114.5	Spun-Up		

Table A-1. Run Log for Subsonic Free-Rolling Wind Tunnel Test of Canard-Control Missile (Continued)

EXPERIMENTAL CANARD - CONTROL MISSILE

RUN NO.	CONFIGURATION: CANARD DEFLECTION (DEG) δ_{C1}	δ_{C2}	δ_{C3}	δ_{C4}	TAIL DEFLECTION (DEG) δ_{T1}	δ_{T2}	δ_{T3}	δ_{T4}	YAW ANGLE (DEG)	Q (PSF)	TEMP. (^oR)	VEL. (FPS)	P (PSIA)	INITIAL CONDITIONS: SPUN-UP	PIN-PULL ANGLE (DEG)	REMARKS
353	-	-	-	-	0	0	0	0	30°	14.97	523.3	112.77	2114.5	Spun-Up		
354	-	-	-	-	0	0	0	0	30°	15.10	524.0	113.35	2114.3		Pin-Pull 0	
355	-	-	-	-	0	0	0	0	25°	15.20	524.0	113.71	2114.3		0	
															CHANGED	TO 5° TAIL CANT
356	-	-	-	-	5	5	5	5	30°	15.08	526.0	113.50	2114.4		-37.5	Undamps with many oscillations to steady-state
357	-	-	-	-	5	5	5	5	25°	15.22	528.2	114.25	2114.3		-30.0	0 to steady-state rate
358	-	-	-	-	5	5	5	5	25°	15.04	529.0	113.67	2114.5		-22.5	4 undamped oscillations to steady-state
359	-	-	-	-	5	5	5	5	0°	15.10	531.2	114.13	2114.4	Spun-Up		Turbine
															END OF	TEST

APPENDIX B

NOMENCLATURE

NOMENCLATURE

C_{ac}, C_{as}	Roll asymmetry coefficients, defined in Equation (6)
C_{jk}	Roll moment coefficients, defined in Equation (6) (see Table 1)
$C_{\ell jk}$	Roll moment coefficients, defined in Equation (5)
C_{ℓ}	Roll moment coefficient (ℓ/QSd)
$C_{\ell}(p)$	Roll moment coefficient variation with missile spin rate
C_{ℓ_p}	Linear roll damping moment coefficient
$C_{\ell_{pj}}$	j^{th} order roll damping moment coefficient, defined in Equation (4)
$C_{\ell_p}(4\gamma)$	Variation of roll damping moment coefficient with roll angle for a four-finned missile (see Table 1)
$C_{\ell_p}(4K\gamma)$	K^{th} order variation of roll damping moment coefficient with roll angle for a four-finned missile (see Table 1)
C_{ℓ_δ}	Fin cant roll moment coefficient
$C_{\ell_\delta}(4\gamma)$	Variation of fin cant moment with roll angle for a four-finned missile (see Table 1)
$C_{\ell_\delta}(4K\gamma)$	K^{th} order variation of fin cant moment with roll angle for a four-finned missile (see Table 1)
$C_{\ell}(\gamma)$	Roll moment coefficient variation with roll angle
$C_{\ell(4\gamma)}$	Induced rolling moment coefficient for a four-finned missile
$C_{\ell(4K\gamma)}$	K^{th} order induced rolling moment coefficient for a four-finned missile, defined in Equation (3) (see Table 1)
d	Missile reference diameter
I_x	Missile axial moment of inertia
p	Missile spin rate, $p = \dot{\gamma}$
Q	Dynamic pressure
S	Missile reference area

S_{jk}	Roll moment coefficient, defined in Equation (6) (see Table 1)
V	Free-stream velocity
α	Angle of attack
γ	Roll orientation angle, measured between reference fin No. 1 and normal component of missile velocity vector
γ_0	Initial roll orientation angle
δ	Fin cant angle
δ_{C1} δ_{C2} δ_{C3} δ_{C4}	Canard deflection angles, defined in Figure 4
δ_{T1} δ_{T2} δ_{T3} δ_{T4}	Tail fin deflection (cant) angles, defined in Figure 4

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